



Homeland
Security

R203

Dear National Fire Academy Student:

Congratulations on your acceptance into the U.S. Fire Administration's National Fire Academy's *Fire Dynamics – Fire Modeling* (R203) course. Your assistance is requested in preparation for this educational opportunity.

This course is dependant upon mathematical calculations. You will not experience a great deal of lecture-based instruction, rather a more instructor led/monitoring approach. This course will be very challenging, yet rewarding. We ask for your commitment to prepare yourself for this opportunity through completion of the Pre-course work assignments that follow.

You will have access to Unit 2: *Mathematical Review*, and Unit 3: *Physics*. In addition, you will have access to the *Mathematical Pre-Course Preparation Review* questions. You should complete all questions prior to notifying us of your pre-course work completion.

You must bring with you a laptop computer that has a minimum of 256 MB RAM, with a Pentium 4 processor. Your PC should also have the Windows 2000 operating system or newer. If you have an Apple type computer, it must have an emulator program.

You will also need to bring with you a scientific calculator for in-course work.

Upon receipt of this notice, you should download the following programs into your PC before arrival for class:

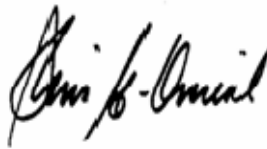
- FDS (Fire Dynamics Simulator)
- Smokeview

These are accessible at: www.fire.nist.gov

Prior to your departure, please ensure with your employing agency that your computer will allow you to run everything, as previous experience has shown that some are limited to administrator rights. Have your IT folks enable the programs, which allows you access.

You alone are responsible for security and maintenance of your equipment. The Academy cannot provide you with computer software, beyond that required in this course, hardware, or technical support to include disks, printers, scanners, etc. In order to cover the amount of material required for this course, completion of individual and/or group assignments and studying after classroom hours will be necessary. Also, evening classes may be conducted to complete all course requirements or to provide instructor led tutorials. A key preparatory component to this course is completion of the pre-course information listed above. Upon completion of these tasks, please notify Mr. Douglas R. Williams, Arson Mitigation Curriculum Training Specialist via e-mail (doug.williams@dhs.gov) or phone: 301-447-1158. You may contact him with any questions or if other information related to the course as needed.

Sincerely,

A handwritten signature in black ink, appearing to read "Denis Onieal", written in a cursive style.

Dr. Denis Onieal, Superintendent
National Fire Academy
U.S. Fire Administration

Enclosure

UNIT 2: MATHEMATICAL REVIEW

TERMINAL OBJECTIVE

Given an explanation of the process, the precourse preparation, and practice problems, the students will be able to solve algebraic and geometric problems correctly.

ENABLING OBJECTIVES

The students will:

- 1. Review the proper use of various signs and symbols involved in fire dynamics.*
 - 2. Use established mathematical practices to solve algebraic equations correctly.*
 - 3. Understand how graphs are created and what data are derived from interpretation of the graphs.*
 - 4. Use and practice conversion of English-based units of measure to the metric system.*
 - 5. Correctly calculate aspects of geometric shapes.*
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ALGEBRA

Brief History

Algebra is a branch of mathematics that permits us to use various symbols (variables) that represent unknown quantities. Algebra's origin dates back to almost 3,000 years ago, when the Babylonians solved quadratic equations using techniques very similar to methods we employ today. The Egyptians also used algebraic methods and solved linear, indeterminate, and quadratic equations. The word "algebra" has ninth-century Arabic roots (*al-jabr*), and refers to the science of restoration and balancing.

Purpose of Using Algebra

Using rules of arithmetic, we can manipulate variables in order to establish relationships and solve for unknown quantities. The student uses algebra in his or her daily life, solving simple problems, such as how much money he or she should budget to travel 400 miles, if his or her car averages 25 miles per gallon (mpg) of gas. The fields of science, medicine, and engineering have used algebra as a foundation to study and answer many questions.

Fire-Related Problems

The study of the dynamics of fire has led to many observations that can be stated algebraically. You must have a thorough understanding of arithmetic operations and basic algebra principles in order to use the fire dynamics formulas.

CONCEPTS OF VARIABLES

The unknown quantities or **variables** are usually represented by a letter (*a*, *b*, *c*, etc.) or a symbol (π , β , γ , θ , etc.). The latter symbols are characters of the Greek alphabet (pi, beta, gamma, and theta) and are common in many of the algebraic equations associated with the study of fire dynamics. You should become familiar with the table of the Greek alphabet listed in the Appendix of this unit.

Values

Solving algebraic equations provides us with numeric values that belong to the set of real numbers. Real numbers include the subsets of rational and irrational numbers.

Real Numbers

Natural numbers: 1, 2, 3, 4

Whole numbers: 0, 1, 2, 3

Integers: . . . -3, -2, -1, 0, 1, 2, 3

Rational numbers: $-\frac{7}{3}$, $\frac{4}{5}$, 0.6, any integer divided by a **non-zero** integer, or any number that can be written in the form of $\frac{a}{b}$, where a and b are integers.

Irrational numbers: $\sqrt{5}$, $\sqrt{14}$, π . All root values and others that cannot be expressed as a rational number ($\frac{a}{b}$).

ALGEBRAIC EXPRESSIONS

Arithmetic expressions (example: $5 + 6$) do not contain any unknowns and can be solved by following the applicable mathematical rules of operations. Algebraic expressions may contain numerous unknowns or variables and are classified according to their complexity. Numbers, symbols, and variables that are contained within an arithmetic expression are referred to as **terms** of the expression. Identifying the degree and type of algebraic expression can assist one when attempting to apply various problem-solving methods.

Monomial expression: (Greek "mono" meaning "one").

Example: $6xy$

Binomial expression: (Greek "bi" meaning "two").

Example: $6xy + 4b$

Trinomial expression: (Greek "tri" meaning "three").

Example: $6xy + 4b + 7$

Polynomial expression: a monomial expression that contains a term with x raised to a whole power.

Examples: $3x^2 + 2x + 4$ (note: $x^0 = 1$, so $4x^0 = 4$)
 $9x^3 + 6x^2 + 3x + 10$

Implied Multiplication

Multiplication of constants or unknowns can be stated in several ways. Traditionally, an \times is used to denote multiplication. When dealing with algebraic expressions, x may be one of the stated variables, which would make use of the traditional multiplication symbol \times confusing. To eliminate this confusion, algebra methods permit expression of multiplication by either a dot " \cdot " or brackets " $()$ ". Multiplication also can be implied when no symbols are present and two terms are adjacent to one another.

Example: $5 \cdot b + 6xy$ (product [result] of 5 "**times**" b is **added** to 6 "**times**" product of x and y)

METHODS FOR SIMPLIFYING EXPRESSIONS

An expression can be replaced or substituted by another that has the same value. Simplification of expressions should be performed by following the **order of operations** described in the following section. Equations are formed when an equals sign (" $=$ ") is placed between two expressions. Inequality symbols (less than: $<$; less than or equal to: \leq ; greater than: $>$; greater than or equal to: \geq) can also separate expressions, which are referred to as inequalities.

Examples: $5b + 2c = 3a - 4$ (equation)
 $5b < 4c + 3$ (inequality)

Simplification of an expression is usually accomplished by using one of the following means:

Summation: the result of adding the **terms** of the **sum**.

Example: $5 + 56 = 61$ (sum)

Difference: subtracting one term from another.

Example: $65 - 8 = 57$ (difference)

Product: multiplying numbers or terms, which are referred to as **factors** of the **product**.

Example: $12 \cdot 8 = 96$ (product)

Quotient: the result of dividing one term or expression by another. The quotient is the resulting value of the operation of division.

Example: $12 \div 3 = \frac{12}{3} = 4$ (quotient)

Grouping symbols: pairs of brackets [], parentheses (), or a line that designates division.

Example:
$$\frac{5(8 + 3)}{(6 - 2)}$$

Powers or exponents: A **power** is a product of equal factors. The factor being repeated is referred to as the **base**. A positive power or exponent states the number of times a base term is multiplied by itself.

Example: $5^3 = (5)(5)(5) = 5 \cdot 5 \cdot 5 = 125$

Absolute value: The **absolute value** of any given number is the distance along a number line from the specified number to the location of zero (0). The absolute value of a number is expressed as the value of a number sandwiched between two vertical lines.

Example: $|-7| = 7$
 If $a \geq 0$, then $|a| = a$
 If $a \leq 0$, then $|-a| = a$

ORDER OF OPERATIONS

Complex arithmetic and algebraic expressions can be simplified using the following rules of order, dictating which operations are performed first. Principles of substitution state that an expression or term can be replaced by another that has the same or equal value. Simplification of expressions should be performed by using the following order of operations.

1. **Simplify the expressions** within each grouping, proceeding from the innermost grouping outward.

Example: $5(3 + 2)$
 $5 \cdot 5 = 25$

2. **Simplify powers** of constants.

Example: $5 \cdot 3^2$
 $5 \cdot 9 = 45$

3. Perform multiplication or division in order, proceeding from the left side of the expression towards the right side.

Example: $5 \cdot 9 - 6 \cdot 4 \div 3$
 $45 - 24 \div 3$
 $45 - 8 = 37$

4. Perform addition or subtraction in order, proceeding from the left to the right side of the expression.

Example: $5 + 6 - 7 + 3 \div 6$
 $(11 - 7) + \frac{3}{6}$
 $4 + \frac{1}{2} = 4\frac{1}{2}$

Activity 2.1**Order of Operations****Purpose**

To practice order of operations.

Directions

1. Work in your table group on the first problem.
2. Be prepared to share your answer with the class.
3. Work in your table group on the second problem.
4. Repeat the process.

Problem Set

1. $2 + 3(5 - 6) =$
2. $9 \div (4 \bullet 7 - 4) \bullet 8 =$
3. $\frac{21 \div 7}{4} \bullet (5 + 2) =$
4. $\frac{4(32 - 8)}{24 \div 2} \div 4 + 5 \div 10 \bullet 4 =$
5. $\left[9 + 4\left(\frac{1}{2} + \frac{2}{1}\right) \bullet [(3 + k) \div 2] - 4 \right] =$

REAL NUMBER OPERATIONS

Most of our daily activities follow some particular set of rules that govern or guide our actions. Algebra also is governed by a set of rules that permit us to operate and solve equations successfully. The following properties of equality are considered true for all real numbers:

Reflexive property: $a = a, b = b$, etc.

Symmetric property: If $a = b$, then $b = a$.

Transitive property: If $a = b$, and $b = c$, then $a = c$.

Addition property: If $a = b$, then $a + c = b + c$ and $c + a = c + b$.

If a is a positive value and b is a negative value, then $a + b = a - |b|$ (absolute value of b).

If $|a| > |b|$, then $a + b$ results in a positive value.

If $|a| < |b|$, then $a + b$ results in a negative value.

If a and b are both negative, add the absolute values of a and b , and assign the sum a negative value: $a + b = -(|a| + |b|)$.

Multiplication property: If $a = b$, then $ac = bc$ and $ca = cb$.

If a is negative and b is positive, then ab is negative.

If a is positive and b is negative, then ab also is negative.

If a and b are both negative values, then ab is positive.

The set of real numbers (rational and irrational) comply with all of the following rules, commonly referred to as "field properties."

Commutative properties: $a + b = b + a$
 $ab = ba$

Associative properties: $(a + b) + c = a + (b + c)$
 $(ab)c = a(bc)$

Identity properties: The number one (1) and zero (0) are unique.

$$a + 0 = a, \quad 0 + a = a$$

$$a \cdot 1 = a, \quad 1 \cdot a = a$$

Inverse properties: For every a , there is a unique real number $-a$. The variable $-a$ is referred to as the additive inverse of a . $a + (-a) = 0$. For every a , except zero (0), there is a unique real number of $1/a$, which is expressed as the "reciprocal" (or multiplicative inverse) of a .

$$a \cdot \frac{1}{a} = 1$$

Distributive Properties: This is one of the more important properties involved in algebra. It permits us to interact between multiplication and addition. The action of the distributive property lets us "distribute" the value a through the sum of the expression $b + c$.

$$a(b + c) = ab + ac, \text{ and } (b + c)a = ba + ca$$

$$a(b - c) = ab - ac, \text{ and } (b - c)a = ba - ca$$

RULES OF MULTIPLICATION

The result of multiplying two or more terms produces an answer, which is commonly referred to as the **product** of the values (or factors). We previously reviewed multiplication involving negative values, stating that multiplication of either two positive values or two negative values results in a positive product. Multiplication of a positive and negative value produces a negative product or answer.

If more than two terms are involved in the multiplication process, the value of the product is dependant upon whether there is an even or odd number of negative values in the expression. If the number of negative values is even (example: 2, 4, 8...), then the value of the product is positive. If the number of negative values is odd (example: 1, 3...), then the value of the product is a negative number.

Multiplication by zero: $a \cdot 0 = 0$ and $0 \cdot a = 0$

Multiplication by -1 : $a(-1) = -a$ and $(-1)a = -a$

Multiplication of expressions containing two algebraic terms (**binomial** expression) is accomplished by applying the **distributive law**.

$$\begin{aligned}(a + b)(c + d) &= a(c + d) + b(c + d) \\ &= ac + ad + bc + bd\end{aligned}$$

This process is also commonly referred to as the **FOIL** method. We multiply two binomial expressions by factoring the **F**irst times first term, **O**utside times outside term, **I**nside times inside term, and **L**ast times last term.

$$\text{Example: } (a - 5)(a - 4) = a^2 - 4a - 5a + 20 = a^2 - 9a + 20$$

General format for squaring binomials (**FOIL**):

$$\begin{aligned}(a + b)^2 &= a^2 + 2ab + b^2 \\ (a - b)^2 &= a^2 - 2ab + b^2 \\ (a + b)(a - b) &= a^2 - b^2\end{aligned}$$

Activity 2.2

Rules of Multiplication

Purpose

To practice rules of multiplication.

Directions

1. Work in your table group on the first problem.
2. Be prepared to share your answer with the class.
3. Work in your table group on the second problem.
4. Repeat the process.

Problem Set

6. $(6 + y)^2 =$ (use distributive law)

7. $(6 + y)^2 =$ (use FOIL method)

8. $x(4 - 5k) + 2 =$

9. $(2k - 3f)^2 =$

10. $3 - 2 \cdot 3(4xy - 2x) - 5 =$

FRACTIONS

Fractions belong to the set of real numbers and are expressed as $\frac{a}{b}$, with b being a nonzero number. All other numbers can be expressed in the form of a fraction (or ratio). Fractions may be expressed in any of the following formats:

$$12 \div 6 = 2 \qquad \frac{12}{6} = 2$$

The process of dividing the **numerator** (top value) by the **denominator** (bottom value) produces a value that is referred to as the **quotient**. Dividing by a number can also be accomplished by multiplying by the nonzero number's **reciprocal**. **Division by zero** is not defined, and since zero has no reciprocal, a value of zero cannot be in the denominator.

$$12 \div 6 = 12 \bullet \frac{1}{6} = \frac{12}{6} = 2$$

The quotient of either two positive or negative terms results in a positive number. The quotient of two terms, where one is positive and the other negative (either in the numerator or denominator), results in a negative number.

Cancellation Law

The cancellation law states that if a factor is present in both the numerator and denominator, then the factor can be eliminated from the expression.

Example: $\frac{ab}{ac} = \frac{b}{c}$

Addition and Subtraction of Fractions

Addition or subtraction of two or more fractions is possible, if the fractions have the same value as the denominator. If the values are different, then the least common denominator must be found by multiplying the values in question by both the top and bottom of each fraction.

Example: $\frac{1}{4} + \frac{1}{4} = \frac{2}{4} = \frac{1}{2}$

In the below fraction, the least common denominator of the values 4 and 6 is 12. Multiplying each fraction by the appropriate number results in both fractions having the same denominator.

Example: $\frac{1}{6} - \frac{1}{4} = \frac{1(2)}{6(2)} - \frac{1(3)}{4(3)} = \frac{2}{12} - \frac{3}{12} = \left(-\frac{1}{12}\right)$

Multiplication and Division of Fractions

Multiplication of fractions involves multiplying each numerator and denominator times the other.

$$\frac{a}{c} \times \frac{b}{d} = \frac{ab}{cd}$$

Example: $\frac{5}{3} \times \frac{4}{7} = \frac{20}{21}$

Division of fractions is simplified by multiplying the numerator fraction by the reciprocal of the denominator fraction. (Invert and multiply.)

$$\frac{a}{c} \div \frac{b}{d} = \frac{a}{c} \bullet \frac{d}{b}$$

Example: $\frac{12}{11} \div \frac{7}{6} = \frac{12}{11} \bullet \frac{6}{7} = \frac{72}{77}$

Activity 2.3**Rules of Fractions****Purpose**

To practice rules of fractions.

Directions

1. Work in your table group on the first problem.
2. Be prepared to share your answer with the class.
3. Work in your table group on the second problem.
4. Repeat the process.

Problem Set

11. $\frac{2}{7} + \frac{4}{3} =$

12. $\frac{3}{4} - \frac{2}{5} + \frac{8}{2} =$

13. $\frac{7k}{4} - \frac{5x}{2} \bullet 4 + \frac{2x}{3} =$

14. $\frac{4}{5} \div \frac{2}{3} \bullet \frac{1}{2} =$

$$15. \quad \frac{\frac{3.45}{1.28}}{4} =$$

$$16. \quad \frac{\frac{5}{6}}{1.14} =$$

EXPONENTIAL POWERS, ROOTS, AND RADICALS

The expression a^n is read as a is the product of itself n times. The base of the exponential expression is a , and n , the exponent is the "power of a ."

$$a^n = a^1 \bullet a^2 \bullet a^3 \dots a^n$$

$$a^4 = a \bullet a \bullet a \bullet a$$

Laws of Exponents

If a and b are real numbers, and m and n are positive integers, then:

$$a^m \bullet a^n = a^{m+n}$$

$$(ab)^m = a^m \bullet b^m$$

$$(a^m)^n = a^{m \cdot n}$$

$$a^0 = 1$$

Negative exponents: If n belongs to the set of natural numbers and $a \neq 0$ then:

$$a^{-n} = \frac{1}{a^n}$$

This rule permits us to "move" exponential expressions from the numerator to the denominator, and vice versa, when **only** the functions of multiplication and division are involved. Exponential signs can be moved by changing the sign of the exponent.

Examples: $a^{-4} = \frac{1}{a^4}$ $\frac{a^3}{b^{-4}} = a^3 \bullet b^4$ $\frac{1}{k^5} = k^{-5}$

$$(ab)^{-1} = \frac{1}{(ab)} \quad \frac{b^3 c^{-2}}{a^{-4}} = \frac{b^3 a^4}{c^2} \quad \frac{z^3}{x^{-4} y^{-2}} = z^3 x^4 y^2$$

The Cancellation Law can be applied to exponents with the same base.

If $n > m$: then $\frac{a^n}{a^m} = a^{n-m}$

If $n < m$ then $\frac{a^n}{a^{m-n}} = \frac{1}{a^m}$

Activity 2.4
Laws of Exponents

Purpose

To practice rules of exponents.

Directions

1. Work in your table group on the first problem.
2. Be prepared to share your answer with the class.
3. Work in your table group on the second problem.
4. Repeat the process.

Problem Set

17. $3^{-4} \bullet 5 =$

18. $\frac{1}{3^2} \bullet \frac{4^2}{5} =$

19. $\frac{x^4 \bullet y^{-2}}{x^{-3}} =$

20. $4^{-2} \bullet 4^2 =$

21. $(1.3k)^4 =$

22. $\frac{2^3}{2^2} =$

23. $\frac{3^2}{3^5} =$

Fractional Exponents

The previous rules for exponents defined the proper actions when the exponent was expressed as an integer. Some formulas in fire dynamics contain exponents that are rational numbers. The following definitions apply to fractional exponents:

If n is a natural number:

$$a^{\frac{1}{n}} = \sqrt[n]{a}$$
$$a^{\frac{-1}{n}} = \frac{1}{\sqrt[n]{a}}$$

If m and n are integers:

$$a^{\frac{m}{n}} = \left(a^m\right)^{\frac{1}{n}} \quad \text{or} \quad \left(a^{\frac{1}{n}}\right)^m \quad \text{or} \quad \sqrt[n]{a^m}$$

Example: If $a = 4$, $m = 2$, and $n = 3$:

$$\begin{aligned} 4^{\frac{2}{3}} &= \sqrt[3]{4^2} \\ &= \sqrt[3]{16} \\ &= 1.5874 \end{aligned}$$

Activity 2.5
Fractional Exponents

Purpose

To practice using fractional exponents.

Directions

1. Work in your table group on the first problem.
2. Be prepared to share your answer with the class.
3. Work in your table group on the second problem.
4. Repeat the process.

Problem Set

24. $5^{\frac{1}{4}} =$

25. $4^{\frac{-1}{3}} =$

Radical Expressions

The expression $\sqrt[n]{a}$ is called a radical, with n being the **index** and a being the **radicand**. The modern calculator has made a detailed understanding of radicals unnecessary for our study of fire dynamics. Reviewing the following rules may help if confronted with equations requiring simplification.

- $\sqrt[n]{a^n} = a$, if n is odd. Example: $= a \cdot \sqrt[3]{a^3}$ so $\sqrt[n]{a^n} = |a|$, is even.

Example: $= \sqrt[3]{3^3} = \sqrt[3]{27} = 3$

- $\sqrt[n]{a \cdot b} = \sqrt[n]{a} \cdot \sqrt[n]{b}$, if $a \geq 0$ and $b \geq 0$

Example: $\sqrt[4]{4 \cdot 64} = \sqrt[4]{256} = 4$
or $\sqrt[4]{4} \cdot \sqrt[4]{64} = 1.414 \cdot 2.828 = 4$

- $\sqrt[n]{\frac{a}{b}} = \frac{\sqrt[n]{a}}{\sqrt[n]{b}}$, if n is odd and $b \neq 0$, or if n is even, when $a \geq 0$ and $b > 0$.

Example: $\sqrt[3]{\frac{64}{4}} = \frac{\sqrt[3]{64}}{\sqrt[3]{4}} = \frac{4}{1.586} = 2.52$, or
 $\sqrt[3]{\frac{64}{4}} = \sqrt[3]{16} = 2.52$

- $\sqrt[m]{\sqrt[n]{a}} = \sqrt[m \cdot n]{a}$ if m and n are both odd; otherwise $a \geq 0$

Example: $\sqrt[3]{\sqrt[5]{45}} = \sqrt[3 \cdot 5]{45} = \sqrt[15]{45} = 1.2888$
or $\sqrt[3]{\sqrt[5]{45}} = \sqrt[3]{2.1411} = 1.2888$

Solving Radical Equations

Simplification of radical equations generally is accomplished by isolating the radical expression, then squaring both sides of the equation in order to eliminate the radical expression. The use of modern calculators has eliminated the necessity to simplify radical equations in some instances, but there may be circumstances when manipulation of a formula is necessary.

Accident investigators attempt to determine a vehicle's speed by measuring the length of skid marks (d). The investigator can use the formula below when the road surface is dry:

$$S = \sqrt{22d}$$

If a vehicle leaves 170 feet of skid marks, then the vehicle's speed is calculated as:

$$S = \sqrt{22d} = \sqrt{22 \bullet 70 \text{ ft}} = \sqrt{3740} = 61.15 \text{ mph}$$

If investigators want to know what the skid-to-stop distance of a vehicle is for a particular speed, the above formula can be manipulated to provide the distance.

$$45 \text{ mph} = \sqrt{22d} \quad \text{Determining distance of skid at 45 mph}$$

$$(45)^2 = (\sqrt{22d})^2 \quad \text{Squaring both sides to isolate } d$$

$$\frac{2225}{22} = \frac{22d}{22} \quad \text{Dividing both sides by 22 to isolate } d$$

$$d = 92.04 \text{ feet of skid for a vehicle traveling at 45 mph}$$

Activity 2.6

Radical Expressions

Purpose

To practice solving radical expressions.

Directions

1. Work in your table group on the first problem.
2. Be prepared to share your answer with the class.
3. Work in your table group on the second problem.
4. Repeat the process.

Problem Set

26. Convert the radical expression into an exponential expression.

$$\frac{1}{\sqrt[3]{8}} =$$

27. $\frac{3}{\sqrt[5]{2^2}} =$

SOLVING ALGEBRAIC EQUATIONS

Equations containing variables may be referred to as **open sentences**. The variable or variables that satisfy the equation, or make the equation true, are referred to as its **solution**. Postulates of equality apply to equations:

- Reflexive property: $a = a$.
- Symmetric property: If $a = b$, then $b = a$.
- Transitive property: permits substitution of values.
If $a = b$, and $b = c$, then $a = c$.
- Substitution property: If $a = b$, then one can substitute b in any place where a is found.

The process of solving an equation requires us to simplify the equation using any of the above postulates, and then transform the equation to create a clearly defined solution. The "golden rule of equations" states that "whatever we do to one side of the equation, we must do to the other." This rule applies to the use of addition, subtraction, multiplication, and division. When employing the use of division, the denominator must not equal zero.

The general strategy for solving equations is to isolate the unknown variable on one side of the equation and then perform the operation that permits a solution. Dividing or multiplying both sides by the coefficient of the unknown allows us to reach a solution.

Example:

$$\begin{aligned}
 22x - 6 &= 5 \\
 22x - 6(+6) &= 5(+6) && \text{[adding (+6) to each side]} \\
 \frac{22x}{22} &= \frac{11}{22} && \text{[dividing both sides by 22 to isolate } x\text{]} \\
 x &= \frac{1}{2}
 \end{aligned}$$

Rational Algebraic Expressions

We previously defined the set of rational numbers as any number that could be expressed as a quotient of integers. A rational algebraic expression is one that can be expressed as a quotient involving polynomials. Simplification of the rational expression occurs when we simplify the polynomial to a point where the greatest factor is one.

Example: $\frac{6xy^3}{7xy} = \frac{6y^2}{7}$ (canceling out terms x and y)

Example: $\frac{y^2 - 2y}{y^2 - 4} = \frac{y(y - 2)}{(y + 2)(y - 2)} = \frac{y}{y + 2}$

(simplify expression)
(root of binomial) then cancel out $(y - 2)$ expression

Activity 2.7

Solving Equations

Purpose

To practice solving equations.

Directions

1. Work in your table group on the first problem.
2. Be prepared to share your answer with the class.
3. Work in your table group on the second problem.
4. Repeat the process.

Problem Set

28. Solve for x .

$$2x + 8 = 4$$

29. Solve for x .

$$x^2 + (16y)^{\frac{1}{2}} = 0$$

30. Solve for k .

$$\frac{7k}{4} - \frac{5x}{2} \cdot 4 + \frac{2x}{3} = 0$$

31. Solve for b .

$$\frac{\sqrt[3]{b}}{6} = 8$$

32. Solve for x .

$$x^{\frac{5}{2}} = \frac{20^{\frac{1}{2}}}{3}$$

33. Solve for k .

$$\sqrt{k} = y^{\frac{2}{3}}$$

Activity 2.8

Formula Conversions

Purpose

To practice converting formulas.

Directions

1. Work in your table group to convert the first formula.
2. Be prepared to share your answer with the class.
3. Work in your table group on the second conversion.
4. Repeat the process.

Problem Set

Solve for \dot{Q} .

$$34. \quad H_f = 0.174 \left(k \dot{Q} \right)^{0.4}$$

$$35. \quad \dot{Q} = \frac{79.18 H_f^{\frac{5}{2}}}{k}$$

UNITS OF MEASURE

English

Common units of measure and weights in the United States are based upon **English customary weights and measures**. The English base units have evolved over time, with influence from the Normans and the Romans, and generally relate to ordinary objects and activities of a particular period.

Length:

- **Inch:** length of 3 barleycorn, base unit of measurement in the English measurement system.
- **Digit:** width of a finger (.75 inches).
- **Foot:** The foot was defined as being 12 inches long during the Norman Conquest of the 11th century.
- **Yard:** Henry I ordered construction of 3-foot "standards," which he called "yards."
- **Fathom:** the distance when a person stretches his/her arms out to each side (6 feet).
- **Mile:** Distance a Roman Legion would travel in 1,000 paces (left and right steps). Usual pace was approximately five feet, resulting in a mile being around 5,000 feet. Our modern mile is 5,280 feet long.
- **Acre:** eighth-century derivation of the amount of a field that could be plowed in a morning, since oxen needed to be rested by afternoon.

Volume:

- **Gallon:** The base unit of volume, and originally was equivalent to the volume of eight pounds of wheat. The American volume of 231 cubic inches was based on the size of an English **wine gallon**. Four **quarts** comprise a gallon, and 2 **pints** equal a quart.
- **Imperial gallon:** The imperial gallon was established as a unit of measure in England in 1824. It is the volume of 10 pounds of water, or 277.42 cubic inches.

- **Peck:** A peck is the equivalent of two gallons.
- **Bushel:** Four pecks equal a bushel.

Weight:

- **Grain:** A **grain** is a base unit in the English system and represents the weight of a single barleycorn, which also served as the base unit for measurements of length. A grain is the equivalent to 64.79891 milligrams, or .00208 ounces.
- **Pound:** A Roman **troy pound** was divided into twelve segments, called **ounces**. Each ounce weighed 480 grains. The European merchants changed the division to 16 ounces, since halves and quarters were whole units. The European (avoirdupois: after the Italian unit of measure) pound was the equivalent of 7,000 grains. This created a difference in the size of ounces between the two systems, with the troy ounce weighing 480 grains, and the avoirdupois ounce weighing 437.5 grains. The troy system is usually limited to precious metals and pharmaceuticals.
- **Long ton:** A British ton, which weights approximately 2,240 pounds--close to the weight of a metric ton.
- **Short ton:** The United States unit of weight, which weighs 2,000 pounds.

Temperature:

- **Fahrenheit:** The **Fahrenheit** temperature scale developed during the early part of the 18th century by Gabriel Fahrenheit. The boiling point was defined as 212 °F (100 °C) and the freezing point set at 32 °F (0 °C).

Power and energy:

- **Foot-pound:** A **foot-pound** is defined as the work that is done when a weight or force of 1 pound is moved over a distance of 1 foot.
- **Horsepower:** The unit defined as **horsepower** was developed by James Watt, and described as the mechanical power that could be accomplished by a horse as 550 foot-pounds of work per second.

- **British thermal unit (Btu):** A Btu is a measure of heat quantity equal to the amount of heat required to raise the temperature of water 1 ° Fahrenheit.

Metric

Scientists and merchants began to express interest in a unified system of weights and measures in the middle of the 18th century. An emerging global economy and a need for a unified method of measurement lead to the acceptance of the **metric system** in the 1790's, the time of the French Revolution. The original units of measure were based on earthly observations. The **meter** was designated to be one ten-millionth of the distance from the equator to the North Pole. The **liter** was the volume of a cubic decimeter, and the **kilogram** was supposed to be the weight of pure water. These values are not exactly true by today's standards since our current methods of measurement are much more exact than in the 18th century.

In 1875, the **Système International d'Unités** adopted the following "base units" of measurement, which serve as the foundation of the metric system:

- Distance: **meter (m)**: The meter is the length of the path traveled by light in vacuum during a time interval of $1/299\,792\,458$ of a second.
- Mass: **kilogram (kg)**: The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram.
- Time: **second (s)**: The second is the duration of 9 192 631 770 periods of radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom.
- Electric current: **ampere (A)**: The ampere is the constant current, which, if maintained in two straight parallel conductors of infinite length and of negligible circular cross-section, and placed 1 meter apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} Newton per meter of length.
- Temperature: **Kelvin (K)**: The Kelvin, a unit of thermodynamic temperature, is the fraction $1/273.16$ of the thermodynamic temperature of the triple point of water.

- Quantity of substance: **mole (mol)**: The mole is the amount of substance of a system that contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12; its symbol is "mol." When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles. <http://physics.nist.gov/cuu/Units/mole.html>
- Intensity of light: **candela (cd)**: The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} hertz and that has a radiant intensity in that direction of $\frac{1}{683}$ watt per steradian.

Derived Units

The metric system has more than 20 other units that are derived from the above "base units" and are referred to as **SI derived units**. Some examples of derived units:

- **Newton (N)**: A force that will produce an acceleration of 1 meter per second per second (1 m/s^2) when applied against a mass of 1 kilogram.
- **Volt (V)**: The pressure that is the difference of electric potential existing across the ends of a conductor carrying a constant current of 1 ampere when the power dissipated is 1 watt.
- **Ohm (Ω)**: Defined as a unit of resistance in a circuit in which a potential difference of one volt creates a current of one ampere; hence, 1 ohm equals 1 volt/ampere.
- **Degree Celsius ($^{\circ}\text{C}$)**: Celsius is the temperature scale where 0° Celsius is the freezing point of water, and 100° Celsius the boiling point. The scale is often referred to as the **Centigrade Scale** since it is divided into 100 units.
- **Joule (J)**: The joule is a unit of energy or work named for James P. Joule. The energy expended by a force of 1 Newton acting through a distance of 1 meter.
- **Watt (W)**: The watt is a unit of power developed by James Watt, and is equal to 1 **joule per second**.
- **Pascal (Pa)**: A Pascal is a unit of atmospheric pressure of 1 Newton per meter squared.

- **Calorie (cal):** The calorie is the amount of energy needed to raise 1 gram of water 1° Centigrade. The temperature of the water is important relative to the actual amount of energy that would be required to raise the water 1° Centigrade. The symbol for calorie may have several different subtexts, such as 15°, 20°, or **mean**, and the value of the constant will be dependant upon this criteria.

SI Symbols

The International System of Units does not use abbreviations. The units each have assigned **symbols** that follow mathematical rules for symbols, rather than rules of traditional abbreviation. Symbols for particular SI units are listed in the Appendix of this unit. The adoption of rules helps to further the quest for uniformity and accuracy in the metric system, and the need for scientists and engineers to communicate effectively. Some of the rules for symbols are

- Symbols are not followed by a period, unless the symbol happens to be at the end of a sentence.
- The letter "s" is never applied to symbols to indicate plurality.
- Symbols are not capitalized, unless the symbol comes from a proper name. Capital and lowercase letters are used frequently as symbols for different units of measure, so use of the correct case is important.
- Watt and Pascal are terms originating from scientists James Watt and Blaise Pascal, respectively.

Exception: Uppercase "L" is used as a symbol for the liter, since lowercase "l" may be confused easily with the number "one."

- The multiplication process is indicated by a raised dot, since symbols should not be placed next to one another. **A • h** and **A h** (space between symbols) are permissible but **Ah** and **amp hr** are not.
- Superscripts ² and ³ indicate that the unit is squared or cubed.
- A slash (solidus) (/) is used to indicate a relationship to other dimensions or units. Only one / is permissible per symbol. SI units for acceleration are expressed as "meters per second per second" but the symbol group **m/s/s** is improper and is better expressed as **m/s²**.

- Symbols should be separated by a space when adjacent to a numeric quantity--example: "10 kg" instead of "10kg."

DIMENSIONS AND UNITS

The dimensions of quantities that we attempt to measure usually are expressed as combinations of the following:

- length (**l**);
- mass (**m**);
- time (**t**);
- electric current (**I**); and
- temperature (**θ**).

The term **dimensions** should not be confused with the term **units**, which is a defined physical quantity. Units for speed of a vehicle usually are expressed as either mph or kilometers per hour (km/h), but the units are actually the result of a relationship of dimensions, namely **length** (or distance) divided by **time**. Gallons or liters per minute is the relationship of the volume (length • length • length) over a given period of time. Understanding dimensions, which may be expressed in any given algebraic equation, will help us in analyzing how to organize, simplify, and solve in order to reach the proper solution.

Dimensional Analysis

Dimensional analysis is a method used for solving problems where conversion of units is permissible since we are dealing with the same dimensions. We usually are asked to find a quantity that defines a dimension such as mass, length, time, etc. Manipulation of the algebraic expression permits "cancellation" of like terms appearing in both the numerator and denominator. The rules of equality (reflexive, symmetric, transitive, substitution) serve as the foundation supporting the methodology of dimensional analysis. The process usually involves converting a known quantity by a conversion factor in order to achieve the desired dimensions of the product or quotient.

Example: How many meters are in 3.6 miles?

$$? \text{ meters} = \frac{3.6 \text{ miles}}{1} \times \frac{5280 \text{ feet}}{1 \text{ mile}} \times \frac{12 \text{ inches}}{1 \text{ foot}} \times \frac{2.54 \text{ cm}}{1 \text{ inch}} \times \frac{1 \text{ meter}}{100 \text{ cm}}$$

Canceling out like terms:

$$? \text{ meters} = \frac{3.6 \cancel{\text{miles}}}{1} \times \frac{5280 \cancel{\text{feet}}}{1 \cancel{\text{mile}}} \times \frac{12 \cancel{\text{inches}}}{1 \cancel{\text{foot}}} \times \frac{2.54 \cancel{\text{cm}}}{1 \cancel{\text{inch}}} \times \frac{1 \text{ meter}}{100 \cancel{\text{cm}}}$$

The resulting product contains the unit dimensions (meter) that we seek.

$$\frac{579363.84 \text{ meters}}{100} = \frac{5793.36384 \text{ meters}}{1} = 5793.36 \text{ meters}$$

Activity 2.9
Dimensional Analysis

Purpose

To practice dimensional analysis.

Directions

1. Work in your table group on the first problem.
2. Be prepared to share your answer with the class.
3. Work in your table group on the second problem..
4. Repeat the process.

Problem Set

36. Convert 10 feet into centimeters.

$$1 \text{ inch} = 2.54 \text{ cm}$$

37. Convert 8 feet into meters.

38. Convert 140 Btu/second to kilojoules.

$$1 \text{ kJ} = 0.94783 \text{ Btu}$$

39. Convert 20 kilojoules/second to watts.

40. Convert 103,000 Btu/hour to kilowatts.

Scientific Notation and Logarithms

It is not uncommon in the field of science to obtain large numbers while attempting to determine a particular outcome. **Scientific notation and logarithms** provide us with a number of tools that help us to manage these large numbers. **Scientific notation** is a means of expressing a number as a value between 1 and 10, multiplied to a power of 10. The form of the scientific notation is

$$m \cdot 10^n, \text{ where } 1 \leq m < 10$$

Examples:

$$\begin{aligned} 4,567,000,000 &= 4.567 \cdot 10^9 \\ 0.00002354 &= 2.354 \cdot 10^{-5} \end{aligned}$$

Logarithms, in practice, are exponents and we usually will encounter two particular types of logarithms (logs). The **common** logarithm of a number is the power that a base of 10 must be raised to. A **natural** logarithm is the power that a base of e ($e = 2.718281828\dots$) must be raised to in order to obtain the desired number.

Examples of numbers expressed as common logarithms (symbol: **log**):

$$\begin{aligned} \text{Log}_{10} \mathbf{100} &= \mathbf{2}, \text{ since } 10^2 = 100 \\ \text{Log}_{10} \mathbf{1000} &= \mathbf{3}, \text{ since } 10^3 = 1000 \\ \text{Log}_{10} \mathbf{573} &= \mathbf{2.758} \end{aligned}$$

Examples of numbers expressed as natural logarithms (symbol: **ln**):

$$\begin{aligned} \text{Log}_e 100 &= 4.606 \\ \text{Log}_e 1000 &= 6.908 \\ \text{Log}_e 573 &= 6.351 \end{aligned}$$

Conversion between natural (**ln**) and common (**log**) logarithms:

$$\ln x = 2.303 \log x$$

Example:

$$\begin{aligned} \ln 10 &= (2.303) \log 10 \\ 2.303 &= (2.303) 1 \end{aligned}$$

Example:

$$\begin{aligned} \ln 100 &= (2.303) \log 100 \\ 4.606 &= (2.303) 2 \end{aligned}$$

Since logarithms function as exponents, the rules of operation for exponents apply to them as well:

Common Logarithm

$$\text{Log } xy = \log x + \log y$$

$$\text{Log } \frac{x}{y} = \log x - \log y$$

$$\text{Log } x^y = y \log x$$

$$\text{Log } \sqrt[y]{x} \log x^{\frac{1}{y}} = \left(\frac{1}{y}\right) \log x$$

Natural Logarithm

$$\ln xy = \ln x + \ln y$$

$$\ln \frac{x}{y} = \ln x - \ln y$$

$$\ln x^y = y \ln x$$

$$\ln \sqrt[y]{x} = \log x^{\frac{1}{y}} = \left(\frac{1}{y}\right) \ln x$$

UNIT CONVERSION AND SYMBOLS

Units of conversion between the English customary system and the International System of Units are especially necessary in the study of fire dynamics. The majority of fire-related equations require values expressed in SI units. With the exception of the United States, the nations of the world and the scientific community have accepted and made the metric system their norm. The conversion factors and formulas listed in the Appendix will aid the student in converting from our American English system to SI units. Students must begin to use metric equivalents in order to become more proficient at analyzing and solving scientifically based problems.

The Appendix also includes a table of the Greek alphabet, and common usages that apply to particular letters. A table of common symbols related to the study of the fire sciences is also included for reference when analyzing and reviewing various research and technical papers. The Conversion Factors tables are included as appendices to permit the student to create a reference guide for field use.

GEOMETRIC PRINCIPLES

The Appendix contains a listing of formulas for determining the area and volumes of numerous shapes, which are common in the study of Geometry. The geometric formulas will assist the student in determining the areas and volumes of structural spaces and furnishings. The tools will help us to organize and develop data to solve fire-related questions such as: How much air is available for combustion? or What is the potential heat release rate of an object?

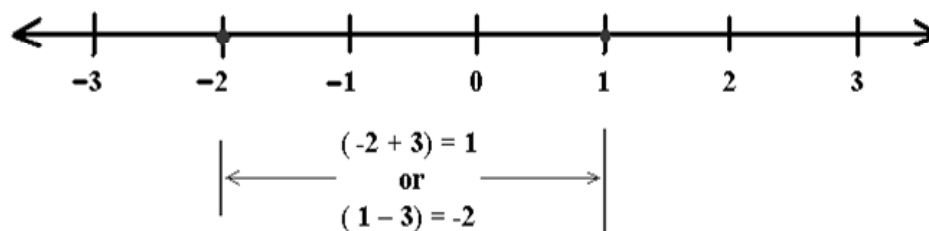
Unit 5: Scene Documentation will address the procedures necessary for proper documentation of fire scenes. The use of principles of area and volume will greatly enhance the student's ability to gather only the necessary measurements, with minimal duplication of effort and time.

Understanding of the relationships of distance and volume also will assist the student in visualizing fire dynamic concepts at the fire scene, and help to develop and test the many potential hypotheses.

COORDINATE SYSTEMS AND GRAPHS

Number Lines

Natural, or counting, numbers can be represented by a number line, which provides an exact point for each number, and in fact for values of all real numbers. The positive numbers are displayed to the right of zero, and the negative to the left. The number line provides us with a visual medium to express and "see" various rules and theories demonstrated. Numeric expressions of addition and subtraction are demonstrated as follows.

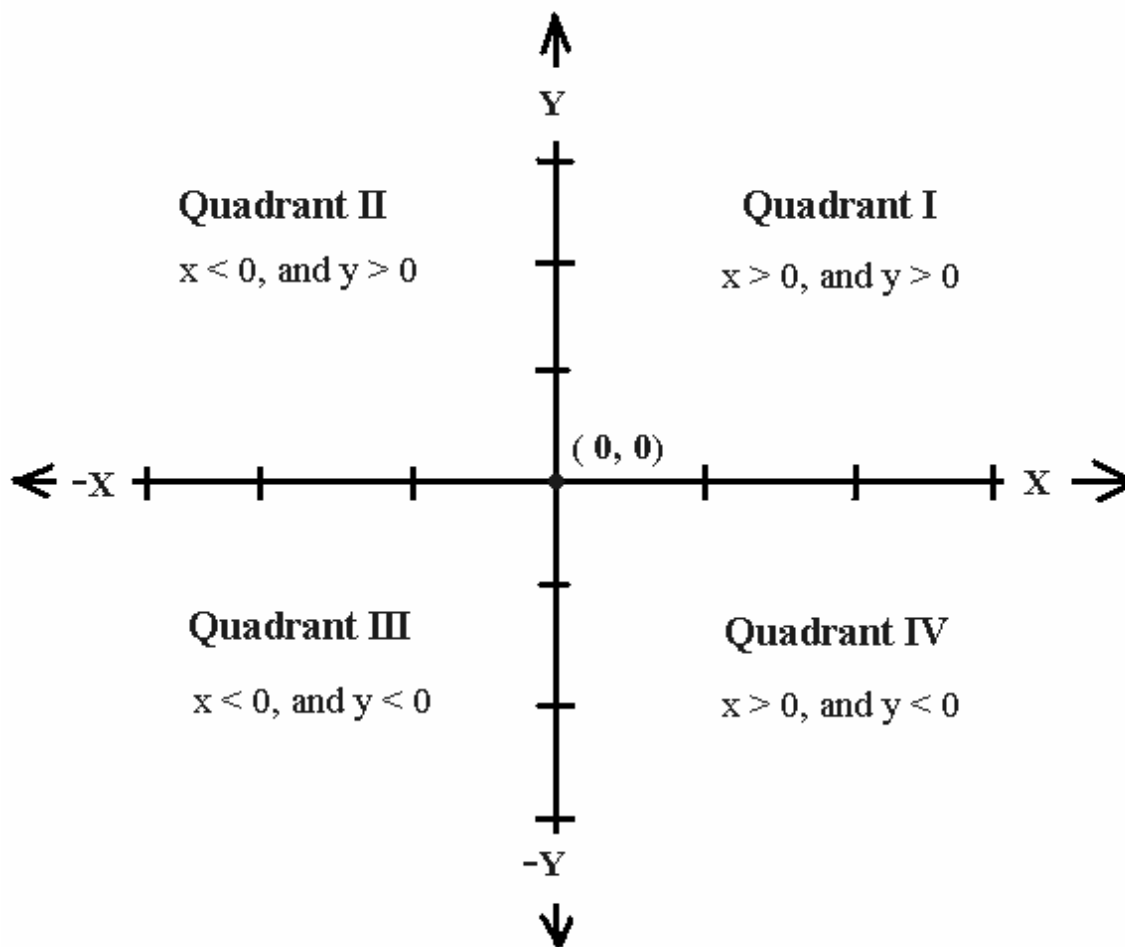


Coordinate Systems

Coordinate systems provide us with a means to organize systems and establish relationships between points within the system. The earth's surface is divided into horizontal (latitude) and vertical (longitude) reference lines, which organize the earth's surface by providing reference points that can assist in navigation and communication. Coordinate systems also support our mathematical practices and assist in establishing relationships when analyzing algebraic expressions and functions.

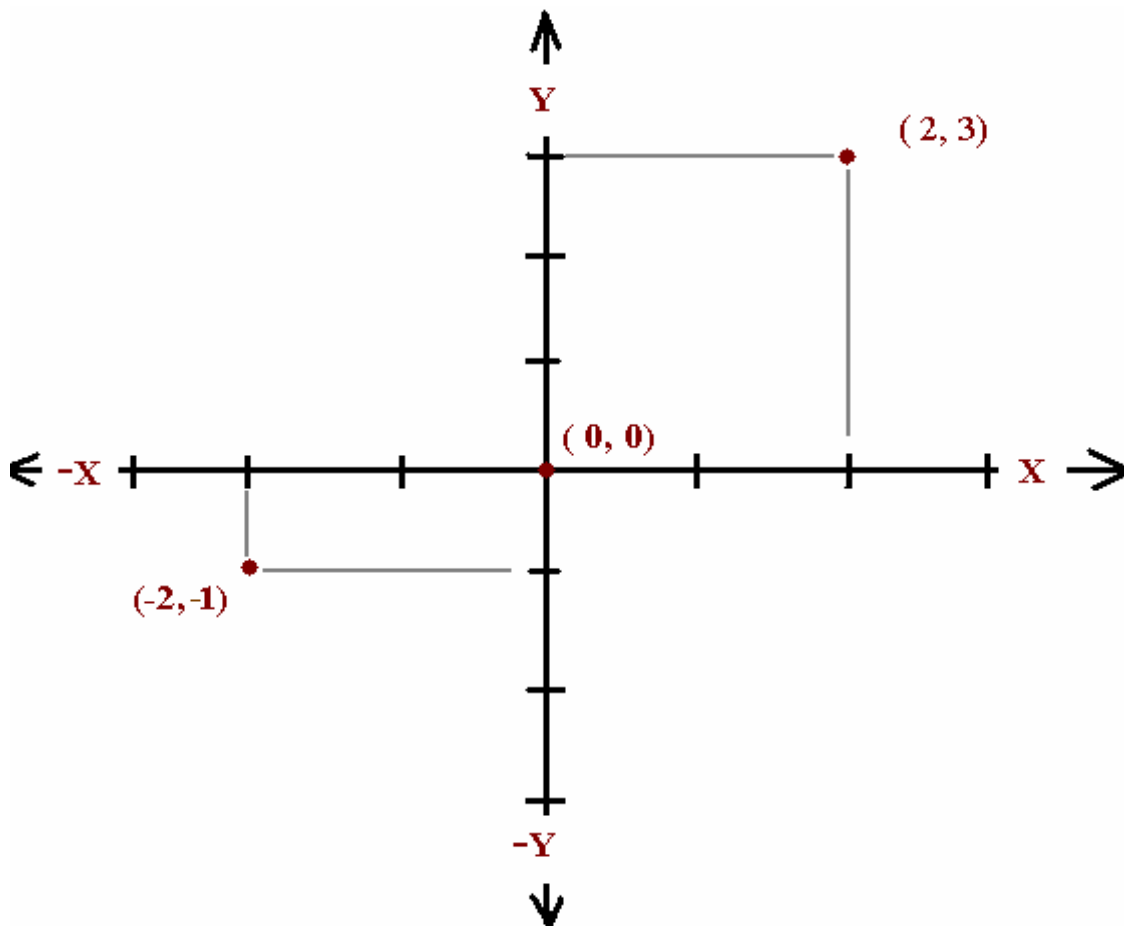
A flat surface that extends into infinity is referred to as a plane. Mathematicians organize the plane and provide orientation by establishing an x -and- y rectangular coordinate system. The horizontal axis is referred to as the x axis, and the vertical axis is named the y axis. This system may sometimes be referred to as the Cartesian coordinate system, which is named after the 17th century French philosopher and mathematician Rene

Descartes. Applying two axes to the plane divides it into four sections, which are referred to as quadrants. The location where the x and y axes intersect is called the origin. The quadrants are labeled with Roman numerals, as indicated in the coordinate system that follows.



CARTESIAN COORDINATE SYSTEMS

Using ordered pairs of numbers [example: $(3, 2)$] permits us to identify unique points on the plane (which may be designated by the letter p). Each point on the coordinate system has its own unique ordered pair. The x coordinate, which is called the **abscissa**, is the first value designated in the ordered pair. The y coordinate, or **ordinate**, is the second value of the ordered pair. Refer to the following graph with the ordered pairs for points $(2, 3)$ and $(-2, -1)$.

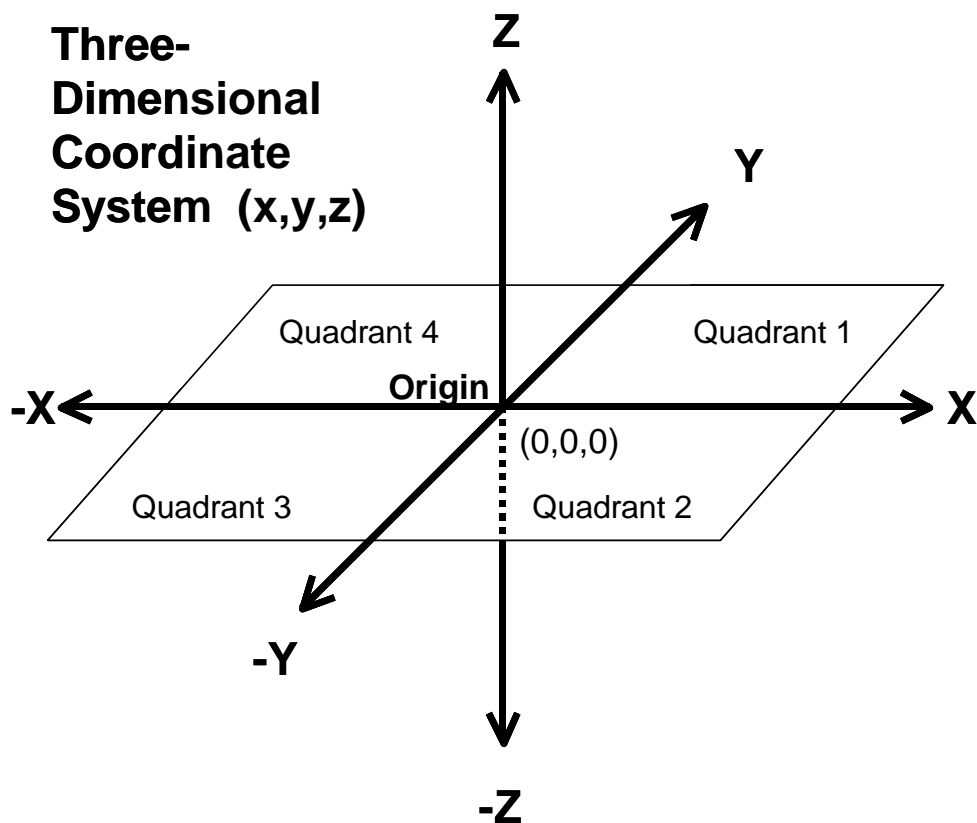


Three-Dimensional Coordinate Systems

The Cartesian Coordinate System provides us with a means to identify points within a single plane in an orderly manner. If we imagine that the floor that we stand on is a single plane, with no depth, then we could organize the area of the floor into quadrants by identifying an x and y axis. This system, unlike our real world, lacks thickness or vertical height. In order to identify points within a three-dimensional system, we must add a third axis, which we will label as z axis. Refer to the diagram that follows. Points defined along the z axis permit us to describe the vertical dimension of an object. In the example of the floor above, we would define the height of the room as a z dimension.

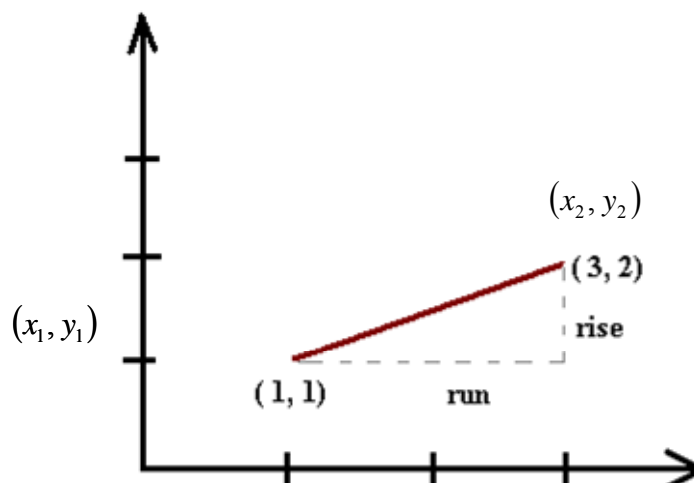
Computer fire modeling requires us to define space in three dimensions. The dimensions or coordinates must be defined as input that the computer can recognize and interpret as a three-dimensional space. Typically, input is entered as data following the previously defined methodology of the Cartesian Coordinate System, with the "height" (vertical measurement) being described by z . This results in a (x, y, z) coordinate system, with the

point (0, 0, 0) referred to as the "origin." If we were to define a box sitting on the floor in front of us, having dimensions of 2 units width, 3 units depth, and 5 units height, the coordinates defining the box would be expressed as (2, 3, 5). This coordinate system serves as the typical means of entering data for most computer models, but the student should be cautioned that the order of the width, depth, and height may be unique to each program.



DETERMINING THE SLOPE OF A LINE

The **slope** of a line in the x -and- y coordinate plane is determined by dividing the **rise** (vertical distance) by the **run** (horizontal distance). When a line has been created as a result of an observation, two points in the coordinate plane are identified and we determine the slope. Determining the equation of a graphed line involves finding the slope of the line and applying the **point-slope form** of the equation of the line. The following example identifies a line's slope, and the corresponding equation of the line.



$$\text{Slope of a line} = \frac{\text{rise}}{\text{run}} = \frac{y_2 - y_1}{x_2 - x_1} \quad (\text{where } x_2 \neq x_1)$$

$$\text{Slope of above line} = \frac{\text{rise} = (2 - 1)}{\text{run} = (3 - 1)} = \frac{1}{2}$$

Expressing Graphed Lines as Equations

After examination of a particular problem or circumstance has produced a graphed observation, we may deem it necessary to have an algebraic equation to express the characteristics of the line. Using the **point-slope** format will help us to define the equation that describes the above line, with slope (m) equaling $\frac{1}{2}$.

The **point-slope** form of a line is $y - y_1 = m(x - x_1)$

So (x_1, y_1) or (1, 1), and the slope (m) = $\frac{1}{2}$

Use the point-slope formula to determine the linear equation of the above graph:

$$\begin{aligned} y - 1 &= x - 1 && (\text{simplifying: } 2y - x = 1) \text{ or} \\ -x &= -2y + 1 && \text{and } x = 2y - 1 \end{aligned}$$

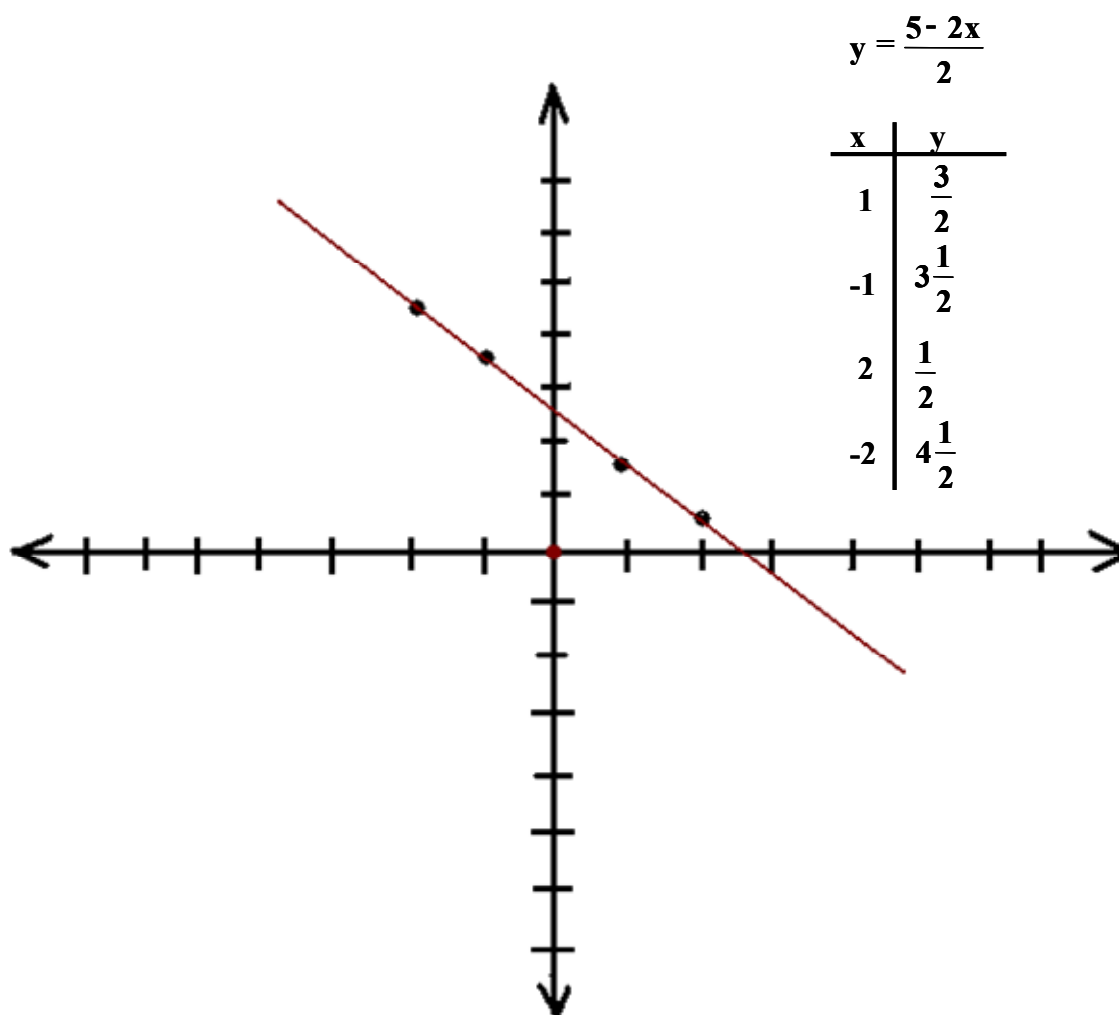
If we insert (x_2, y_2) into the point-slope formula, the linear equation is the same as above.

Graphing Linear Equations

Linear equations involving two variables can be graphed after entering random values for one of the unknowns and solving for the second. Solutions to the equations of the form below will produce values for both x and y , which graph as a straight line.

$$ax + by = c \quad (\text{where both } a \text{ and } b \neq 0)$$

Usually two values will suffice to determine the orientation of the line, but a minimum of three values is a good idea in order to assure that the equation is linear. The graph below displays the graphing of the equation:



Solving Two Equation Systems with x and y Variables

The **substitution method** provides us with a process that isolates the y value, and then solves for x . After having determined the value of x , the value of y is determined. Following the below steps generally will result in the same values for both x and y , which defines the intersecting point of the two linear equations. If a solution is not reached, then the two linear equations are parallel lines. If more than one solution set satisfies the equations, then the equations define the same line.

- isolate y on one side of the formula, so that it equals an algebraic expression defined by x ;
- substitute the resulting value of y into the other formula, which results in a equation involving only x ;
- solve for x ; and
- insert the value of x into either of the original equations and solve for y .

Example of substitution method:

$$8x + 6y = 76 \quad \text{and} \quad 12x - 6y = 24$$

$$6y + 76 - 8x$$

$$\frac{y}{3} = \frac{76 - 8x}{6} = \frac{38 - 4x}{3}$$

Substituting the value of y into the second question:

$$12x - 6\left(\frac{38 - 4x}{3}\right) = 24$$

$$12x - 2(38 - 4x) = 24$$

$$12x - 76 + 8x = 24$$

$$12x + 8x - 24 = 76$$

$$20x = 100 \quad \text{so } x = 5$$

Substituting $x = 5$ into either equation:

$$8(5) + 6y = 76$$

$$40 + 6y = 76$$

$$6y = 76 - 40$$

$$6y = 36$$

$$y = 6$$

The **elimination method** for solving two equation systems with the variables x and y involves **multiplication** of either one or both of the equations so that the coefficients of the value of y are the same. Through either addition or subtraction, the coefficients of y are eliminated to leave us solving for x . When a solution for x is found, then we repeat the above process and solve for the value of y .

Example:

$8x + 6y = 76$ (adding the above equations where the values of y are already self-canceling)

$$\underline{12x - 6y = 24}$$

$$20x = 100$$

$x = 5$ so $y = 6$ (same solutions were reached with the substitution method above)

Linear Functions

A function, expressed as $f(x)$ (read as the function of x) is similar to a machine that does work for us. For each number that we put into the function, a unique number is derived for the output. We define the function of the linear equation based upon observations for a particular problem we are trying to solve.

If the value of y is dependant upon the value of x , then we can write the equation:

$$y = f(x)$$

We previously discussed and used the speed formula, which determined the speed of a vehicle, based upon the length of a vehicle's skid marks. The formula is a function, dependant upon the value of d , the distance.

$$S = f(d) = \sqrt{22d}$$

EXAMPLE OF APPLICATION OF FUNCTIONS AND EQUATION SYSTEMS TO REAL WORLD SITUATIONS

Chief Jones and Lieutenant Smith were in the lunch room one afternoon discussing their states of fitness. Lieutenant Smith knew that the Chief Jones had just completed his required 1 mile run in 12 minutes, which was the bare minimum allowed by the fire department. Lt. Smith was teasing the chief, inferring that if he wouldn't stop at the donut shop every morning, perhaps he could decrease his time. Feeling full of himself, and

knowing that he consistently averaged 7-minute miles during his daily run, Lt. Smith challenged Chief Jones to a race. He told the chief that he could start from the donut shop and run to the police station; while Lt. Smith would start from the fire station and run to the police station

All of the fireman knew that the distance from the fire station to the police station was 3.6 miles, and one phone call to the police department revealed that the donut shop was 2.1 miles from the police department. The chief was unsure if he should accept the challenge, and told Smith that he would "think it over."

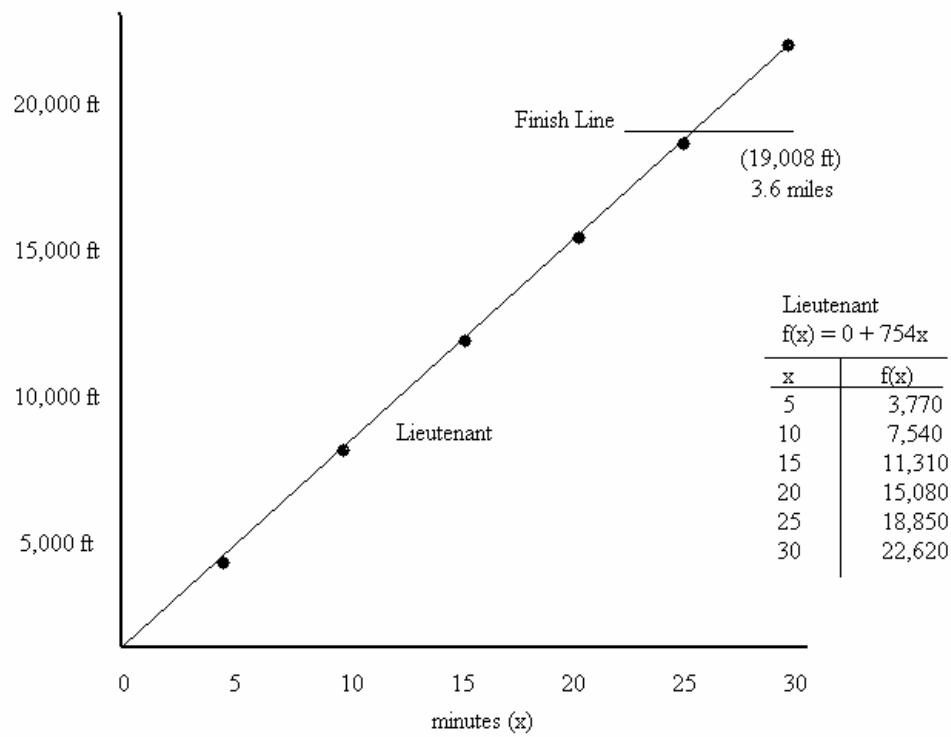
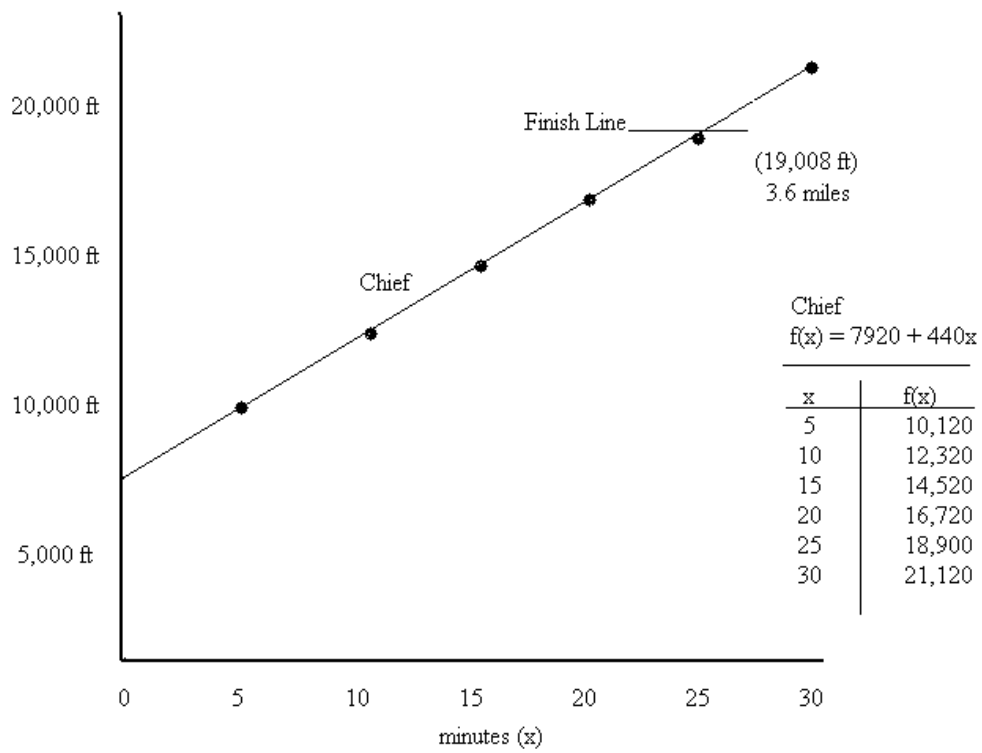
Chief Jones returned to his office and began to ponder the challenge. He knew that in order to determine if the contest was feasible, he would have to develop relationships dealing with the average speed for both himself and Smith. After all, he was the chief, and if he took up the bet, winning was the only option. Chief Jones deduced the following relationships using the concept of functions.

The total distance of the race is 3.6 miles, or 19,008 feet ($3.6 \text{ miles} \times 5,280 \text{ ft/mile}$). The donut shop is 1.5 miles from the fire station ($3.6 \text{ miles} - 2.1 \text{ miles}$). The length of the chief's lead over Smith at the start of the race is 1.5 miles times 5,280 feet/mile, which equals 7,920 feet. If Chief Jones runs 12-minute miles for his length of the race, he will average 440 feet per minute. Lt. Smith, on the other hand, runs a 7-minute mile, which equates to 754 feet per minute. Based upon these factors, the chief established the following relationships:

Chief = $f(x) = 7,920 + 440x$, where x is the time in minutes, and 7,920 feet is his head start.

Lt. = $f(x) = 0 + 754x$, where x is the time in minutes and the value 0 represents the start line at the fire station.

Setting the distance equal to y , the chief decided to graph the linear functions, by determining the distance traveled for both runners, at 5-minute intervals.



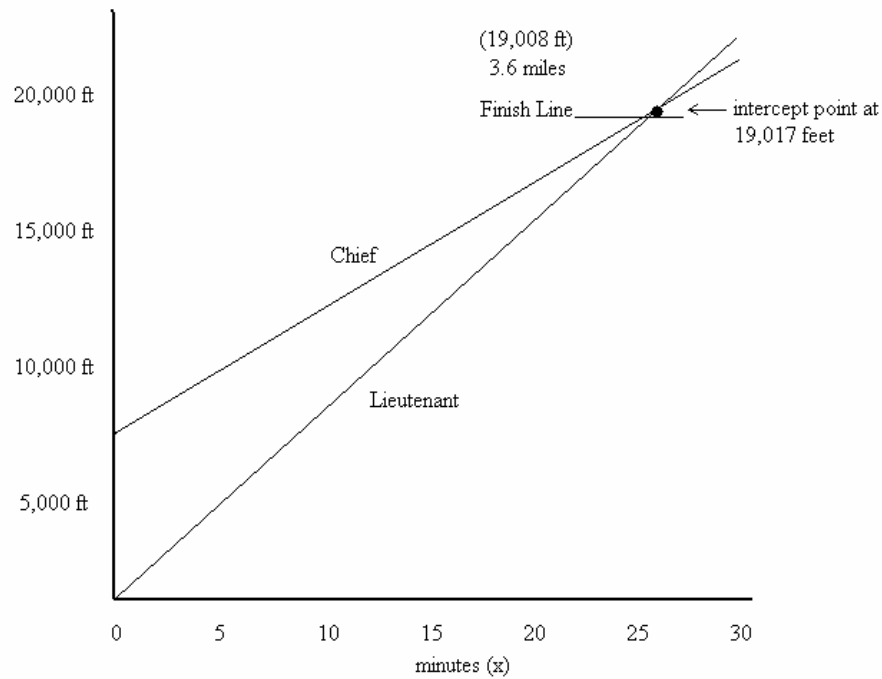
Unsure as to whether he should accept the wager, the chief decided to investigate further. The chief knew that if he set both linear equations equal to each other, then the solution would tell him when the two runners would meet, and since the distance traveled (y) is dependant upon the variable for time (x in minutes), he could write the equation as:

<p>Chief Jones $y = f(x) = 7,920 + 440x$</p>	<p>Lieutenant Smith $y = f(x) = 0 + 754x$</p>
$7,920 + 440x = 0 + 754x$ (reflexive and symmetric properties)	
$7,920 + 440x - (440x) = 0 + 754x - (440x)$	
$7,920 = 314x$	
$\frac{7,920}{314} = x$	
$25.222 = x$ (minutes)	

Having learned the time at which Lt. Smith would catch up to him, and knowing that the race is 3.6 miles (19,008 feet) long, Chief Jones wanted to determine at what point along the race course the two runners would meet. Substituting the time (x) of 25.222 into the functions should provide him with the same distance for both himself and Smith.

<p>Chief Jones</p> $ \begin{aligned} y &= f(x) = 7920 + 440x \\ &= 7920 + 440(25.222 \text{ min}) \\ &= 7920 + 11097.68 \\ &= \mathbf{19017.68 \text{ feet}} \end{aligned} $	<p>Lieutenant Smith</p> $ \begin{aligned} y &= f(x) = 0 + 754x \\ &= 0 + 754(25.222 \text{ min}) \\ &= 0 + 19017.388 \\ &= \mathbf{19017.388 \text{ feet}} \end{aligned} $
--	--

Chief Jones also decided to graph the two functions to see if the point where the two meet is past the finish line. According to the following graph, and checking both equations, Chief Jones learned that if all went as planned, Lt. Smith would catch up to him, 9 feet past the finish line. Chief Jones' decision: too close to call!



COMMON FIRE DYNAMICS FORMULAS

The following formulas will serve as a foundation into exploring the science of fire dynamics. The student should not waste his or her time determining what the formula's meaning is at this time, since an opportunity will be afforded to him/her in Unit 7: Mathematical Modeling. This brief introduction will serve to familiarize the student with proper algebraic methods necessary in order to reach the correct answer.

- Height of flame above the surface of burning materials:

$$H_f = 0.174(kQ_{(kW)})^{0.4}$$

- Determining the **heat release rate** necessary for a known flame height:

$$\dot{Q} = \frac{79.18H_f^{\frac{5}{2}}}{k}$$

- The minimum-sized fire that will result in flashover in a given room is a function of the ventilation opening provided:

$$HRR_{fo} (kW) = (750 A_o)(h_o)^{0.5} = 7.8A_w$$

- Heat release rate for flashover when the room dimensions are known:

$$HRR_{fo} (kW) = (378 A_o)(h_o)^{0.5} + 7.8A_w$$

- Spherical radiant energy release from a flame:

$$\dot{q}'' = \frac{X_r \dot{Q}}{4\pi c^2}$$

SUMMARY

You should be proficient with algebraic concepts in order to begin the process of studying dynamic principles of combustion. Completion of Activity 2.2 will permit each student to practice manipulation of various algebraic expressions, as well as the previously referenced formulas. Failure to have a thorough understanding of the algebraic concepts, which serve as the foundation for the course of study to follow, will hamper your progress.

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- <http://www.chemtutor.com/number.html>
- <http://www.hyperphysics.phy-astr.gsu.edu/hbase/alg3.html>

APPENDIX

GREEK ALPHABET

A α	ALPHA (AL-fuh) First letter of the Greek alphabet.
B β	BETA (BAY-tuh)
Γ γ	GAMMA (GAM-uh)
Δ δ	DELTA (DEL-tuh)
E ε,ϵ	EPSILON (EP-sil-on) The second form of the lowercase epsilon is used as the "set membership" symbol.
Z ζ	ZETA (ZAY-tuh)
H η	ETA (AY-tuh)
Θ θ	THETA (THAY-tuh) Symbol for temperature.
I ι	IOTA (eye-OH-tuh)
K κ	KAPPA (KAP-uh)
Λ λ	LAMBDA (LAM-duh) Symbol for half-life.
M μ	MU (MYOO)
N ν	NU (NOO)
Ξ ξ	XI (KS-EYE)
O ο	OMICRON (OM-i-KRON) Rarely used because it looks like an "o."
Π π	PI (PIE) The lowercase Pi is used to represent the number that is the ratio of the circumference of a circle to its diameter. Uppercase Pi is used as the "product" symbol.
P ρ	RHO (ROW)
Σ σ,ς	SIGMA (SIG-muh) The capital Sigma is used as the "summation" symbol.
T τ	TAU (TAU) Lowercase Tau is used as a symbol for torque.
Υ υ	UPSILON (OOP-si-LON)
Φ φ,ϕ	PHI (FEE) The two versions of lowercase Phi are used interchangeably.
X χ	CHI (K-EYE)
Ψ ψ	PSI (SIGH)
Ω ω	OMEGA (ohMAY-guh) Last letter of the Greek alphabet. Capital omega is the symbol for ohms in measurement of electricity. Lowercase omega is used as symbol for rotational velocity in the field of physics.

Source: www.mathacademy.com/pr/prime/articles/greek/index.asp

UNITS OF MEASUREMENT

The following tables are provided for the purpose of familiarizing the student with the metric system.

SI Unit Prefixes:

giga	(G)	meaning	10^9	deci	(d)	meaning	10^{-1}
mega	(M)	meaning	10^6	centi	(c)	meaning	10^{-2}
kilo	(k)	meaning	10^3	milli	(m)	meaning	10^{-3}
hecto	(h)	meaning	10^2	micro	(μ)	meaning	10^{-6}
deka	(da)	meaning	10^1	nano	(n)	meaning	10^{-9}

Comparison of SI Units of Length:

10 millimeters (mm)	=	1 centimeter (cm)
10 centimeters	=	1 decimeter (dm) (100 millimeters)
10 decimeters	=	1 meter (m) (1,000 millimeters)
10 meters	=	1 dekameter (dam)
10 dekameters	=	1 hectometer (hm) (100 meters)
10 hectometers	=	1 kilometer (km) (1,000 meters)

Comparison of SI Units of Area:

100 square millimeters (mm ²)	=	1 square centimeter (cm ²)
100 square centimeters	=	1 square decimeter (dm ²)
100 square decimeters	=	1 square meter (m ²)
100 square meters	=	1 square dekameter (dam ²)
100 square dekameters	=	1 square hectometer (hm ²)
100 square hectometers	=	1 kilometer (km ²)

Comparison of SI Units of Liquid Volume:

10 milliliters (mL)	=	1 centiliter (cL)
10 centiliters	=	1 deciliter (dL) (100 milliliters)
10 deciliters	=	1 liter (1,000 milliliters)
10 liters	=	1 dekaliter (daL)
10 hectoliters	=	1 kiloliter (kL) (1,000 liters)

Comparison of SI Units of Volume:

1,000 cubic millimeters (mm ³)	=	1 cubic centimeter (cm ³)
1,000 cubic centimeters	=	1 cubic decimeter (dm ³)
1,000 cubic centimeters	=	1,000,000 cubic millimeters
1,000 cubic decimeters	=	1 cubic meter (m ³)

Comparison of SI Units of Mass:

10 milligrams (mg)	=	1 centigram (cg)
10 centigrams	=	1 decigram (dg) (100 milligrams)
10 decigrams	=	1 gram (g) (1,000 milligrams)
10 grams	=	1 dekagram (dag)
10 dekagrams	=	1 hectogram (hg) (100 grams)
10 hectograms	=	1 kilogram (kg) (1,000 grams)
1,000 kilograms	=	1 megagram (Mg) or metric ton

Comparison of U.S. Units of Length:

12 inches (in)	=	1 foot (ft)
3 feet	=	1 yard
16 ¹ / ₂ feet	=	1 rod (rd) (also a pole, or perch)
40 rods	=	1 furlong (fur) (660 feet)
8 furlongs	=	1 U.S. statute mile (mi) (5,280 feet)
1,852 meters	=	approx. 6076.11549 feet
" "	=	1 international nautical mile

Comparison of U.S. Units of Area:

144 square inches (in ²)	=	1 square foot (ft ²)
9 square feet	=	1 square yard (yd ²) (1,296 in ²)
160 square rods	=	1 acre (43,560 square feet)
640 acres	=	1 square mile (mi ²)

Comparison of U.S. Units of Volume:

1,728 cubic inches (in ³)	=	1 cubic foot (ft ³)
27 cubic feet	=	1 cubic yard (yd ³)

Comparison of U.S. Units of Liquid Volume:

4 gills (gi)	=	1 pint (pt) (28.875 cubic inches)
2 pints	=	1 quart (qt) (57.75 cubic inches)
4 quarts	=	1 gallon (gal) (231 cubic inches)
" "	=	8 pints (32 gills)

Comparison of U.S. Units of Dry Volume:

2 pints (pt)	=	1 quart (qt) (62.200 6 cubic inches)
8 quarts	=	1 peck (pk) (537.605 cubic inches)
" "	=	16 pints
4 pecks	=	1 bushel (bu) (2150.42 cubic inches)
" "	=	32 quarts

Apothecary's Units of Liquid Volume:

60 minims (min)	=	1 fluid dram (fl dr)
" "	=	0.2256 cubic inch
8 fluid drams	=	1 fluid ounce (fl oz)
" " "	=	1.804 7 cubic inches
16 fluid ounces	=	1 pint (pt)
2 pints	=	1 quart (qt) (57.75 cubic inches)
" "	=	32 fluid ounces (256 fluid drams)
4 quarts	=	1 gallon (ga) (231 cubic inches)
" "	=	128 fluid ounces (1,024 fluid drams)

Avoirdupois Units of Mass:

*** The "grain" has the same mass in the avoirdupois, troy, and apothecaries unit of measure systems.

27 ¹¹ / ₃₂ grains	=	1 dram (dr)
16 drams	=	1 ounce (oz)
" "	=	437 ¹ / ₂ grains
16 ounces	=	1 pound
" "	=	256 drams
" "	=	7,000 grains
100 pounds	=	1 hundredweight (cwt)
20 hundredweights	=	1 ton (short)
" "	=	2,000 pounds

CONVERSION FACTORS

Underlined values are exact. All other values are rounded to some degree, a factor which decreases in significance as the decimal places are increased.

Units of Length:

Units	Inches (in)	Feet (ft)	Centimeters (cm)	Meters (m)
1 inch	<u>1</u>	0.083 333 33	<u>2.54</u>	<u>0.025 4</u>
1 foot	<u>12</u>	<u>1</u>	<u>30.48</u>	<u>0.304 8</u>
1 yard	<u>36</u>	<u>3</u>	<u>91.44</u>	<u>0.914 4</u>
1 mile	<u>63 360</u>	<u>5 280</u>	<u>160 934.4</u>	<u>1609.344</u>
1 centimeter	0.393 700 8	0.032 808 40	<u>1</u>	<u>.01</u>
1 meter	39.370 08	3.280 840	<u>100</u>	<u>1</u>

Units of Length--Survey Measure:

Units	Feet	Rods	Miles	Meters
1 link	<u>0.66</u>	<u>0.04</u>	<u>0.000 125</u>	0.201 168 4
1 foot	<u>1</u>	0.060 606 06	0.000 189 393	0.304 800 6
1 rod	<u>16.5</u>	<u>1</u>	<u>0.003 125</u>	5.029 210
1 mile	<u>5 280</u>	<u>320</u>	<u>1</u>	1609.347
1 meter	3.280 833	0.198 838 4	0.000 621 369	<u>1</u>

Underlined values are exact. All other values are rounded to some degree, a factor which decreases in significance as the decimal places are increased.

Units of Area:

Units	Square Feet (ft²)	Square Miles (mi²)	Square Centimeters (cm)	Square Meters (m²)
1 square foot	<u>1</u>	3.587 006 x 10 ⁻⁸	<u>929.030 4</u>	<u>0.092 903 04</u>
1 square yard	<u>9</u>	3.228 306 x 10 ⁻⁷	<u>8361.273 6</u>	<u>0.836 127 36</u>
1 square mile	<u>43 560</u>	<u>1</u>	<u>25 899 881</u> <u>103.36</u>	<u>2 589 988.110</u> <u>336</u>
1 square centimeter	0.001 076 391	3.86 102 2 x 10 ⁻¹¹	<u>1</u>	<u>0.0001</u>
1 square meter	10.763 91	3.861 022 x 10 ⁻⁷	<u>10 000</u>	<u>1</u>

Units of Volume:

Units	Cubic Inches (in³)	Cubic Feet (ft³)	Cubic Yards (yd³)
1 cubic inch	<u>1</u>	0.000 578 703 7	0.000 021 433 47
1 cubic foot	<u>1728</u>	<u>1</u>	0.037 037 04
1 cubic yard	<u>46 656</u>	<u>27</u>	<u>1</u>
1 cubic centimeter	0.061 023 74	0.035 314 67	0.000 001 307 951
1 cubic decimeter	61.023 74	0.035 314 67	0.001 307 951
1 cubic meter	61 023.74	35.314 67	1.307 951
Units	Milliliters (cubic centimeters)	Liters (cubic decimeters)	Cubic Meters
1 cubic inch	<u>16.387 064</u>	<u>0.016 387 064</u>	<u>0.000 016 387 064</u>
1 cubic foot	<u>28 316.846 592</u>	<u>28.316 846 592</u>	<u>0.028 316 846 592</u>
1 cubic yard	<u>764 554.857 984</u>	<u>764.554 857 984</u>	<u>0.764 554 857 984</u>
1 cubic centimeter	<u>1</u>	<u>0.001</u>	<u>0.000 001</u>
1 cubic decimeter	<u>1000</u>	<u>1</u>	<u>0.001</u>
1 cubic meter	<u>1 000 000</u>	<u>1000</u>	<u>1</u>

Underlined values are exact. All other values are rounded to some degree, a factor which decreases in significance as the decimal places are increased.

Units of Capacity of Volume--Dry Volume Measure:

Units	Cubic Inches (in³)	Cubic Feet (ft³)	Liters (L)	Cubic Meters (m)
1 dry pint	<u>33.600 312 5</u>	0.019 444 63	0.550 610 5	5.50 610 5 x 10 ⁻⁴
1 dry quart	<u>67.200 625</u>	0.038 889 25	1.101 221	0.01 101 221
1 peck	<u>537.605</u>	0.311 114	8.809 768	0.008 809 768
1 bushel	<u>2 150.42</u>	1.244 456	35.239 07	0.035 239 07
1 cubic inch	<u>1</u>	5.78 703 7 x 10 ⁻⁴	0.016 387 06	1.638 706 x 10 ⁻⁵
1 cubic foot	<u>1728</u>	<u>1</u>	28.316 85	0.028 316 85
1 liter	61.023 74	0.035 314 67	<u>1</u>	<u>0.001</u>
1 cubic meter	61 023.74	35.314 67	<u>1 000</u>	<u>1</u>

Units of Capacity or Volume--Liquid Volume Measure:

Units	Liquid Pints	Liquid Quarts	Gallons	Cubic Inches
1 fluid ounce	<u>0.062 5</u>	<u>0.031 25</u>	<u>0.007 812 5</u>	<u>1.804 687 5</u>
1 liquid pint	<u>1</u>	<u>0.5</u>	<u>0.125</u>	<u>28.875</u>
1 liquid quart	<u>2</u>	<u>1</u>	<u>0.25</u>	<u>57.75</u>
1 gallon	<u>8</u>	<u>4</u>	<u>1</u>	<u>231</u>
1 cubic foot	59.844 16	29.922 08	7.480 519	<u>1728</u>
1 milliliter	0.002 113 376	0.001 056 688	2.64 172 1 x 10 ⁻⁴	0.061 023 74
1 liter	2.113 376	1.056 688	0.264 172 1	61.023 74

Underlined values are exact. All other values are rounded to some degree, a factor which decreases in significance as the decimal places are increased.

Units of Capacity of Volume--Liquid Volume Measure:

Units	Cubic Feet	Milliliters	Liters
1 fluid ounce	0.001 044 379	29.573 53	0.029 573 53
1 liquid pint	0.016 710 07	473.176 5	0.473 176 5
1 liquid quart	0.033 420 14	946.352 9	0.946 352 9
1 gallon	0.133 680 6	3785.412	3.785 412
1 cubic inch	0.000 578 703 7	16.387 06	0.016 387 06
1 cubic foot	<u>1</u>	28 316.85	28.316 85
1 milliliter	0.000 035 314 67	<u>1</u>	<u>0.001</u>
1 liter	0.035 314 67	<u>1000</u>	<u>1</u>

Units of Mass:

Units	Short Tons	Long Tons	Kilograms	Metric Tons
1 avoirdupois ounce	<u>0.000 031 25</u>	2.790 179 $\times 10^{-5}$	<u>0.028 349 523</u> <u>123</u>	<u>2.834 952 312</u> <u>5</u> $\times 10^{-5}$
1 avoirdupois pound	0.000 5	4.46 428 6 $\times 10^{-4}$	<u>0.453 592 37</u>	4.535 923 7 $\times 10^{-4}$
1 short ton	<u>1</u>	0.892 857 1	<u>907.184 74</u>	<u>0.907 184 74</u>
1 long ton	<u>1.12</u>	<u>1</u>	<u>1016.046 908 8</u>	<u>1.016 046 908</u> <u>8</u>
1 kilogram	0.001 102 311	9.84 206 5 $\times 10^{-4}$	<u>1</u>	<u>.0001</u>
1 metric ton	1.102 311	0.984 206 5	<u>1000</u>	<u>1</u>

Underlined values are exact. All other values are rounded to some degree, a factor which decreases in significance as the decimal places are increased.

Units of Mass:

Units	Avoirdupois Pounds	Milligrams	Grams	Kilograms
1 grain	$1.428\,571 \times 10^{-4}$	<u>64.798 91</u>	<u>0.064 798 91</u>	$\frac{6.479\,891}{\times 10^{-5}}$
1 avdp. dram	0.003 906 25	<u>3887.934 6</u>	<u>3.887 934 6</u>	$\frac{0.003\,887\,934}{6}$
1 avdp. ounce	<u>0.062 5</u>	<u>28 349.523 125</u>	<u>28.349 523 125</u>	$\frac{0.028\,349\,523}{125}$
1 troy/apoth. ounce	0.068 571 43	<u>31 103.476 8</u>	<u>31.103 476 8</u>	$\frac{0.031\,103\,476}{8}$
1 avdp. pound	<u>1</u>	<u>453 592.37</u>	<u>453.592 37</u>	<u>0.453 592 37</u>
1 troy pound	0.822 857 1	<u>373 241.721 6</u>	<u>453.592 37</u>	<u>0.453 592 37</u>
1 milligram	$2.204\,623 \times 10^{-6}$	<u>1</u>	<u>0.001</u>	<u>0.000 001</u>
1 gram	0.002 204 623	<u>1000</u>	<u>1</u>	<u>0.001</u>
1 kilogram	2.204 623	<u>1 000 000</u>	<u>1000</u>	<u>1</u>

Temperature Conversion Formulas:

degrees Fahrenheit	°C to °F	$F = C \cdot (1.8) + 32$
degrees Celsius or Centigrade	°F to °C	$^{\circ}\text{C} = \frac{^{\circ}\text{F} - 32}{1.8}$ or $^{\circ}\text{C} = (^{\circ}\text{F} - 32) \cdot \frac{5}{9}$
degrees Rankine	°F to °R	$R = F + 459.69$
Kelvin	°F to K	$K = C + 273.16$

TEMPERATURE COMPARISONS AND CONVERSION FORMULAS

Fahrenheit (°F)	Celsius (°C)	Kelvin (K)	Rankine (°R)
$T(F) = T(C)(1.8) + 32$	$T(C) = (T(F) - 32)/1.8$	$T(K) = T(C) + 273.16$	$T(R) = T(F) + 459.69$
-148 °F	-100 °C	-173.16 K	311.69 °R
-58 °F	-50 °C	223.26 K	401.69 °R
-4 °F	-20 °C	253.16 K	455.69 °R
0 °F	-17.77 °C	255.99 K	459.69 °R
14 °F	-10 °C	263.16 K	463.69 °R
32 °F	0 °C	273.16 K	491.69 °R
50 °F	10 °C	283.16 K	509.69 °R
71.6 °F	22 °C	295.16 K	531.29 °R
86 °F	30 °C	303.16 K	545.69 °R
100 °F	37.77 °C	310.93 K	559.69 °R
392 °F	200 °C	473.16 K	851.69 °R
500 °F	260 °C	533.16 K	959.69 °R
1000 °F	533.77 °C	810.93 K	1459.69 °R
1500 °F	815.55 °C	1088.71 K	1959.69 °R
1832 °F	1000 °C	1273.16 K	2291.69 °R
2000 °F	1093.33 °C	1366.69 K	2459.69 °R

NOMENCLATURE RELATED TO COMBUSTION

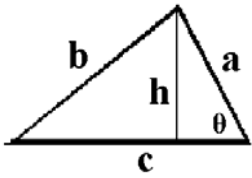
A	Area (m ²)
A ₀	Ignition area (m ²)
A _v	Area of ventilation opening (m ²)
Δh _c	Heat of combustion (kJ/Kg)
h	Height
m	Mass (kg)
\dot{m}	Mass loss rate (kg/s)
\dot{m}''	Mass loss rate per unit area (kg/m ²)
q	Heat release rate (kW)
\dot{q}''	Heat release rate (heat flux) per unit area (kW/m ²) (Btu/hr ft ²)
t	Time (s)
<i>SFPE Fire Protection Engineering. First Edition. pg 2-14.</i>	
J	Joule, SI unit of energy
ρ	Density (kg/m ³) or (lb/ft ³)
Q	Energy (kJ) or (Btu)
\dot{Q}	Energy release rate (kW) (Btu/hr)
c	Specific heat (J/kg - °C) (Btu/lb-°F)
k	Thermal conductivity (W/m - °C) (Btu/hr -ft-°F)
α	Thermal diffusivity (m ² /s)
P	Pressure in pascals (N/m ²) (lb/in ²)
N	Newton, SI unit of force
W	Watt, SI unit of power or work (1 W = 1 joule/sec)
<i>Principles of Fire Behavior. James Quintiere. Delmar, 1997. pg 234-5.</i>	

CONVERSION FACTORS FOR COMBUSTION

Density (ρ)	$1 \text{ kg/m}^3 = 0.06243 \text{ lb/ft}^3$
Energy (J)	$1 \text{ kJ} = 0.94783 \text{ Btu}$ $1055 \text{ J} = 1 \text{ Btu}$ $1 \text{ Btu} = 778.16 \text{ ft} \cdot \text{lb}$
Energy release rate (\dot{Q})	$1 \text{ W} = 3.4121 \text{ Btu/hr}$
Heat flow rate (\dot{q})	$1 \text{ W} = 3.4121 \text{ Btu/hr}$
Heat (joule, Btu)	$1 \text{ kJ} = 0.94783$ $1 \text{ Btu} = 1055 \text{ J}$ $1 \text{ Btu} = 252 \text{ cal}$ $1 \text{ kcal} = 4182 \text{ J}$ $1 \text{ Btu raises } 1 \text{ lb of water } 1^\circ\text{F at } 68^\circ\text{F}$ $1 \text{ cal raises } 1 \text{ g of water } 1^\circ\text{C at } 20^\circ\text{C (68}^\circ\text{F)}$ $1 \text{ kcal raises } 1 \text{ kg of water } 1^\circ\text{C at } 20^\circ\text{C}$
Heat flow rate per unit area (\dot{q}) (heat flux)	$1 \text{ W/cm}^2 = 0.317 \text{ Btu/hr} \cdot \text{ft}^2$ $1 \text{ W/cm}^2 = 10 \text{ kW/m}^2$
Power or work (W)	$1 \text{ W} = 1 \text{ Joule/s}$
Pressure (P)	$1 \text{ atm} = 14.69595 \text{ lb/in}^2$ $1 \text{ atm} = 1.01325 \times 10^5 \text{ N/m}^2$
Specific Heat (c)	$1 \text{ kJ/kg} \cdot ^\circ\text{C} = 0.23884 \text{ Btu/lb} \cdot ^\circ\text{F}$
Thermal Conductivity (k)	$1 \text{ W/m} \cdot ^\circ\text{C} = 0.5778 \text{ Btu/hr} \cdot \text{ft} \cdot ^\circ\text{F}$
Thermal Diffusivity (α)	$1 \text{ m}^2/\text{s} = 10.7639 \text{ ft}^2/\text{s}$

GEOMETRY FORMULAS

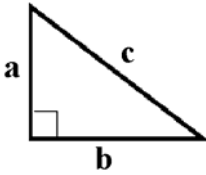
Triangle



$$A = \frac{1}{2}(bh)$$

$$h = a \sin \theta$$

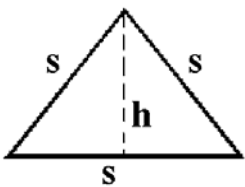
Right Triangle



Pythagorean Theorem

$$c^2 = a^2 + b^2$$

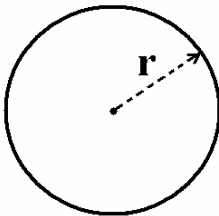
Equilateral Triangle



$$A = \frac{\sqrt{3}(s^2)}{4}$$

$$h = \frac{\sqrt{3}(s)}{4}$$

Circle

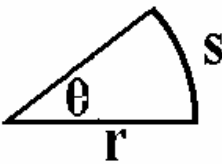


$$A = \pi r^2$$

Circumference:

$$C = 2\pi r$$

Sector of Circle

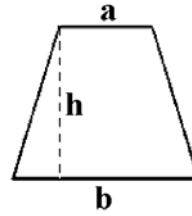


θ = radius

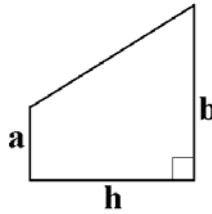
$$A = \frac{\theta r^2}{2}$$

$$s = r\theta$$

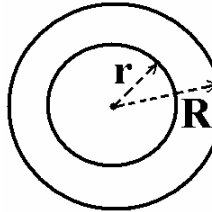
Trapezoids



$$A = \frac{h}{2}(a + b)$$

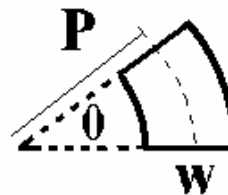


Circular Ring



$$A = \pi (R^2 - r^2)$$

Sector of Circular Ring

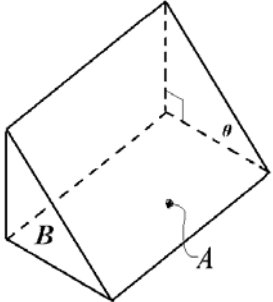
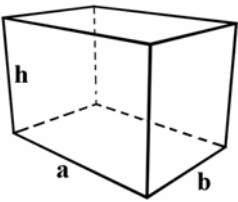
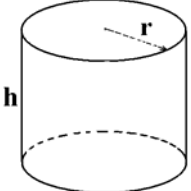
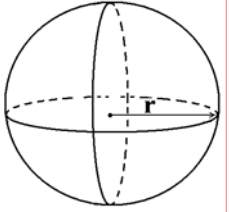
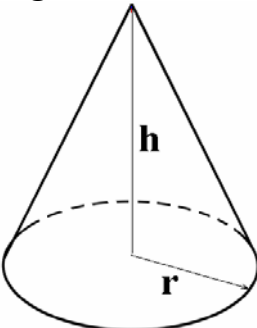
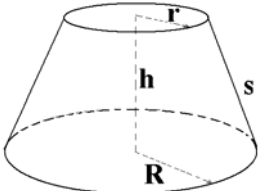


P = average radius

W = width of ring, θ = radius

$$A = \theta P W$$

GEOMETRY FORMULAS

<p>Wedge A = area of upper face of wedge B = area of base of wedge</p>  <p>$A = B \sec \theta$</p>	<p>Cube</p>  <p>$V = abh$ Area of Surface = $2ab + 2ah + 2bh$</p>
<p>Cylinder</p>  <p>$V = \pi r^2 h$ Lateral surface area $= 2\pi r h$</p>	<p>Sphere</p>  <p>$V = \frac{4}{3}(\pi r^3)$</p>
<p>Right Circular Cone</p>  <p>$A = \pi r \sqrt{r^2 + h^2}$ $V = \frac{\pi r^2 h}{3}$</p>	<p>Frustum of Right Circular Cone</p> <p>$V = \frac{\pi(r^2 + rR + R^2)h}{3}$</p> <p>Lateral surface area = $\pi s(r + R)$</p> 

UNIT 3: PHYSICS

TERMINAL OBJECTIVE

The students will be able to explain physical principles associated with fire development.

ENABLING OBJECTIVES

The students will:

- 1. Review the mechanics of fire growth and relate those principles to the candle.*
 - 2. Review physical principles that are related to fire growth.*
 - 3. Articulate how fire grows and progresses.*
-

INTRODUCTION

Although humans have used fire as a tool since the Stone Age, we did not have the ability to analyze or describe it quantitatively with any degree of accuracy until the 1970's. Fire dynamics is based upon known observations previously discovered in physics and chemistry. The underlying principles of our study of fire have existed for several hundred years, with work of Bernoulli and Plank having relevance to the phenomenon of fire in our present-day studies.

Prior to 1970, interest about the physical principles of fire focused primarily on the effects of ship fires during World War II. Scientists and fire investigators were limited to describing qualitative terms such as "how big" or "how fast" was the fire. During the 1970's research began to focus on how to quantifying fire, with significant work from individuals at various laboratories and universities, including the National Institute for Standards and Technology (NIST) in Gaithersburg, Maryland. Early studies focused on invention of devices that would measure heat release values for "bench-scale" samples of materials. Assumptions were made relative to the full-scale or real-life fire situations using these data. Determining what effect fire will have on modern building materials and occupant furnishings that are exposed to fire and hot gases is a complex process. Using data from bench-scale tests in order to predict fire's behavior (predictive analysis) is much less accurate due to the multitude of variables involved with full room or structure involvement.

Attempts to develop full-scale testing devices began in the 1980's when it became apparent to scientists that the heat release rates (HRR) of fires are critically important in understanding how fire grows. The study of fire is complex and requires knowledge of heat transfer, chemistry, fluid mechanics, and thermodynamics. This unit will discuss some of these principles briefly in order to provide a greater understanding of the foundations supporting current fire modeling techniques.

CANDLES

In 1826, Michael Faraday began a series of lectures at the Royal Institute in England. The lectures were presented to young adults and focused on science. In 1860, he presented one of his more famous lecture series, *The Chemical History of a Candle*. The lecture described the working phenomenon of candles with a level of understanding of the properties of heat transfer that is comparable to our knowledge of the subject today.

In our study of the principles of heat transfer; we will examine the burning process of a candle, which is an excellent model of a laminar diffusion flame.

Lighting the wick of the candle results in a sustained flame on the wick. Radiated heat from the flame begins to soften and melt the paraffin wax [a hydrocarbon ($C_{20}H_{42}$)]. The melted wax is drawn up the wick by capillary action (Michael Faraday: "capillary attraction"). When the liquid wax is exposed to the high temperatures of the flame, it is vaporized into a combustible fuel. Vaporizing the paraffin wax (process of pyrolysis) occurs in the lower portion of the flame, where the liquid wax meets the flame. The rising vapors of paraffin wax are consumed in the combustion process of the flame. The candle flame rises upwards as a result of the principle of buoyancy, since the combustion gases and heat are warmer and lighter than the surrounding (room air) atmosphere. The process continues and is accentuated by the fresh incoming air drawn into the flame region to fill in for the rising products of flame combustion. This process permits a continuous supply of oxygen (O_2) into the diffusion flame of the candle.

The candle flame has several distinct areas, distinguishable by the change in color within the flame plume. As the paraffin is vaporized, it rises up into the flame region and is premixed with the fresh oxygen coming in from the sides and below the flame. This results in the bottom section of the flame appearing blue in color. The proper fuel-air ratio into this area results in clean combustion, with little soot. If we insert a spoon in this area, very little soot will be deposited due to the proper proportioning of fuel to air created thorough combustion. This fuel-rich vapor has not begun the process of being broken down by the heat of the flame.

The darker luminous zone, which comprises the inner bottom half of the candle flame, is the region where the chemical bonds of the paraffin fuel are broken down by the actions of heat. This permits the pyrolyzed paraffin fuel to mix with atmospheric air as the pyrolyzed fuel migrates towards the oxygen and forms a mixture. The mixing action of the fuel and oxygen, seeking to equalize themselves (diffuse) with their surrounding environment, follows the principles of Fick's Law, which states

that a given species (e.g., in connection with fire, oxygen, fuel, CO_2) will move from a high to low concentration in the mixture. A drop of blue ink in a glass of water will eventually diffuse into the water to give a blue tinge. Oxygen in air will move to the flame where it has a concentration of zero as it is consumed in the reaction. Fuel is transported into the opposite side of the flame by the same process. The combustion products diffuse away from the flame in both directions.¹

The yellow-to-white luminous zone of the candle is the region where soot (carbon atoms) is present and produces luminosity as it combusts with oxygen. Unburned carbon atoms eventually will escape the high temperature of the flame zone and combine with O_2 to form carbon dioxide (CO_2). A lighter halo exists around the majority of the flame, almost translucent in appearance. This area is the outermost region of combustion, where oxygen and pyrolyzed paraffin mix efficiently with very little soot present.

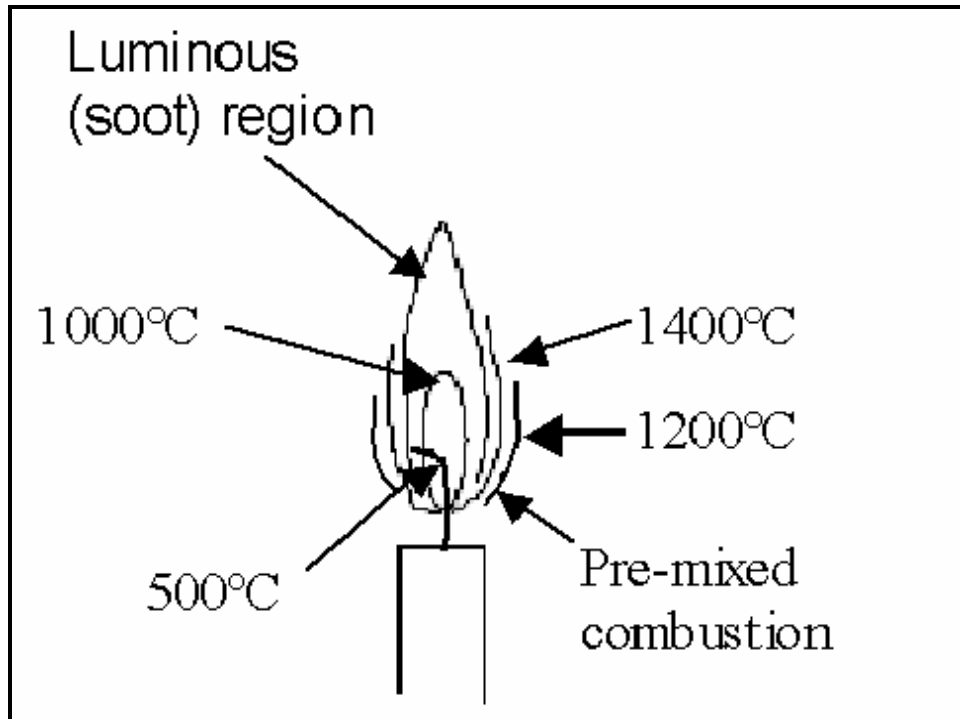


Figure 3-1
Candle Flame

Activity 3.1

Candles

Purpose

To provide hands-on experience with the mechanics and structure of the candle flame

Directions

1. Clear off your table.
2. You will be given one candle per table. Ensure that your candle is secure in its base.
3. Light the candle when it has been placed on the table.
4. Use one spoon and dampened cloth per table.
5. The instructor will proceed to demonstrate each exercise at the front of the classroom, one step at a time. Your table group should complete the exercise as demonstrated.

Exercises

1. Placing a spoon into the blue luminous zone just above the wick produces little soot due to the lack of carbon atoms present that have not reached the breaking of the chemical bonds of pyrolyzed fuel.
2. If the spoon is held at the tip of the candle's flame, large amounts of soot and carbon deposits are observed. Soot is present in the upper luminous zone of the candle flame due to heat breaking the chemical bonds of the paraffin wax vapors. The spoon intercepts the carbon atoms, prior to their bonding with free oxygen molecules and forming carbon dioxide (CO_2).
3. A spoon held in a vertical position against the side of the candle flame limits fresh air intake into the candle fire plume. Shadow heat patterns left on the spoon reveal the outlines of both the inner and outer zones of combustion regions. Note that little soot is present.
4. The shape of the candle flame is well defined and linear in nature due to the rising of cooler air from below, causing the flame to stay compact and confined.

5. If the rising heat from the candle is observed at 1 foot above the candle, it appears undulating, or turbulent.
6. Extinguishing the candle results in white vapors trailing off of the wick. Introducing an open flame to the vapors causes ignition of the vaporized paraffin fuel and the flame jumps back to the candlewick.

LAWS OF CONSERVATION

The Laws of Conservation are fundamental principles of mechanics that serve as the guiding basis for all branches of science. We will discuss these principles briefly in hope that that you will have a better understanding of the foundations that support the complex relationships developed by scientists and engineers.

Scientists use certain terms as a means of communicating their ideas about universal theories, and we will review a few of these prior to examination of the laws of conservation and thermodynamics. A **system** is defined as the portion of our universe that we are interested in studying. The **system** generally will have prescribed confines and matter within it. In order to isolate a particular phenomenon that is under consideration, the **system** is most often considered "closed." A **closed system** is isolated from the effects of the outside world, with matter and energy remaining constant within it, and the effects of gravity and other energy and matter "shut out." A room with no windows or doors containing a known amount of combustible items and liters of air, would represent a closed system. An **open system** permits exchange of matter and energy between it and the outside **surroundings**, so the system can gain and lose energy and/or matter over time. A room with an open window and door that entrains fresh air from outside, and ventilate products of combustion and heat to the outside would be considered an **open system**. When the **system** and its **surroundings** are combined together, they form the **thermodynamic universe** for the particular process under review.

Conservation of Momentum

The total momentum ($m_{\text{ass}} \bullet v_{\text{velocity}}$) of a system is said to be constant or "conserved." At any time, the sum of the momentum of all objects within a system will remain constant (total momentum = $mv_1 + mv_2 + mv_n$). If we observe momentum in one direction of the system, then there must be an equal force in the opposite direction. Conservation of Momentum accounts for the symmetry that is observed in our world.

- **Newton's First Law:** An object will remain at rest, or in motion in a straight line, unless it is acted upon by an external force.
- **Newton's Second Law:** A change in an object's motion will result in an increase in acceleration.
- **Newton's Third Law:** All internal forces of a system are generated in opposite pairs, so the acceleration of the center of mass of an isolated system is zero.

Conservation of Energy

The energy (or capacity to do work) within a system remains constant. "Energy is neither created nor destroyed." The energy can be transformed from one form to another, but the total energy of the system remains unchanged.

$$Q + W' = \Delta U + \Delta E$$

The process of combustion decomposes a substance, with the energy of the chemical bonds of the substance released as heat energy and products of combustion.

- **electric circuits:** Ohm's law (voltage);
- **heat and thermodynamics:** First Law of Thermodynamics; and
- **fluids:** Bernoulli's equation;

Conservation of Angular Momentum

The magnitude and velocity of angular momentum [moment of inertia (I) • velocity (v)] within an isolated system remains constant. If one part of a system is given angular momentum, then another part of the system must possess the same angular momentum, but in the opposite direction. "For every action, there is an opposite and equal reaction."

PRINCIPLES OF THERMODYNAMICS

Energy

Energy is defined as the capacity to do work, or extract heat. Energy is expended in order to move an object from one point to another, or to raise the temperature of a system. Energy may appear in various forms and is either stored (potential energy), or in motion (kinetic energy), or the potential energy between molecules of a substance (**internal energy**). The Law of Conservation of Energy states that at any moment in time, the sum of the potential and kinetic energy of any object remains the same.

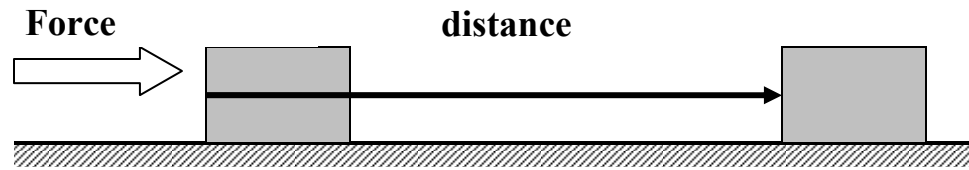
Table 3-1
Potential and Kinetic Energy

Potential energy	Kinetic energy
Electric battery (electric energy)	Electron transfer to power electric windows
Water stored in a water tower	Running water from shower
Diesel fuel in vehicle tank (chemical)	Powers internal combustion engine
Steam (thermal)	Powers steam turbine

Consider the action of a tennis ball that is dropped onto a ceramic floor. The ball will bounce off the floor and continue to bounce. The height of each bounce will be less than the last, until all motion ceases and the ball rests on the floor. The ball held in the hand has stored potential energy, due to its height and the pull of gravity. Once the ball is dropped, the stored potential energy is converted to kinetic energy of the fall. After striking the floor, the ball begins to rise, gradually losing its kinetic energy and having potential energy (pull of gravity) to fall again. At any point in time, the total sum of the potential and kinetic energy, and friction of compression and floor resistance are theoretically equal. When the ball ceases to move, the energy that provided the initial movement has been converted to thermal energy as a result of the processes of compression of the ball as it bounces and friction from the interaction with the floor. The ball's original kinetic energy has been converted into thermal energy stored within the ball and in the floor.

Work

Work is defined as the product of the external force on a body (mass) and the distance that the force acts. Figure 3-2 is true for constant applications of force. If movement of a body does not occur when a force is applied, then we cannot state that work has been accomplished. If the object moves in a direction that is not consistent with the applied force, then work is still accomplished, but only in the length and direction of the result. A block that is moved 5 meters by an applied force of 8 Newtons is the equivalent of 40 joules (mN) of work.



$$\text{Work} = \text{Force (pounds or Newtons)} \cdot \text{distance (feet or meters)}$$

Figure 3-2
Work, Force, and Distance

Power is a term that describes a **rate of doing work** or using energy. **Velocity** is a dimension involving time and distance. In cases where the force is constant and inline with the direction of the velocity, the formulas for power are

$$\text{SI units } P_{\text{ower}} = \text{Newtons} \cdot \text{meters/second} = \text{Joules/second} = \text{Watts}$$

$$P_{\text{ower}} = \text{pounds} \cdot \text{feet/second} = \text{ft lb/s} = \text{horsepower (hp)}$$

If the force is not inline with the direction of the velocity then the formula for instantaneous power is the product of the force and velocity times the cosine of the angle between the two:

$$P_{\text{instantaneous}} = F_{\text{orce}} \cdot \cos \theta \cdot v$$

Heat

Heat is defined as the **process** of transfer of energy from systems or objects of higher temperature to ones of lower temperature. The term **heat** describes an energy transfer resulting from a difference in temperatures of various objects. Objects do not contain heat; rather they possess internal energy. It is **improper** to state that objects or systems possess "heat." Objects having higher energy transmit the energy to objects of lower energy. The process of "sharing" or losing some of an object's internal energy is perceived as thermal heat, or a process of **heating**. Unit 2: Mathematical Review reviewed four different types of temperature scales: Fahrenheit, Celsius, Rankin, and Kelvin. **Temperature** is a measure of the heat generated from the kinetic energy within a system or object. It is not a measure of the total energy potential of the object. Two objects with the same temperature, coal and water for example, will not have the same internal energies, or specific heat values (ability of substance to store energy), although the potential chemical energy are vastly different when oxidized.

Work, Heat, and Energy

The **calorie** is the unit of heat energy in the metric system. Measurement of heat is called **calorimetry**. A calorie (or gram calorie) is the amount of heat required to raise the temperature of 1 gram of pure water, 1 degree Celsius ($^{\circ}\text{C}$). One kilocalorie will raise the temperature of 1 kilogram of water, 1 $^{\circ}\text{C}$. The kilocalorie also is used in determination of energy produced by consumption of food. In this case, one kilocalorie is referred to as a calorie, the amount of energy that the food passes on to the body. The actual amount of energy that is required to raise the temperature of water is dependent on the mean system temperature. It is common to see a reference relative to what specific energy value is applicable to the referenced calorie. The use of a capital letter in the designation of Calorie indicates 1,000 units of small calories.

Table 3-2
Work, Heat, and Energy

Calorie	Common ref.	Temp range Raises T from-to	joules
4 $^{\circ}$ calorie	Small calorie (or therm)	3.5 $^{\circ}\text{C}$ to 4.5 $^{\circ}\text{C}$	4.204
15 $^{\circ}$ calorie	Normal calorie	14.5 $^{\circ}\text{C}$ to 15.5 $^{\circ}\text{C}$	4.185
"mean" avg. calorie	1,100th of energy required to raise temp.	0 $^{\circ}\text{C}$ (melting point) to 100 $^{\circ}\text{C}$ (boiling point)	4.190

Heat and **Work** are both capable of providing energy to systems. If we heat and compress two equal volumes of air, our measurement of the final state of internal energy cannot distinguish which process (or combination of processes) created the increased internal energy. In 1843, James Joule performed an experiment which showed that 1 calorie of heat equaled 4.186 joules of mechanical energy, proving that there was a relationship between work and heat energy. Refer to Figure 3-3.

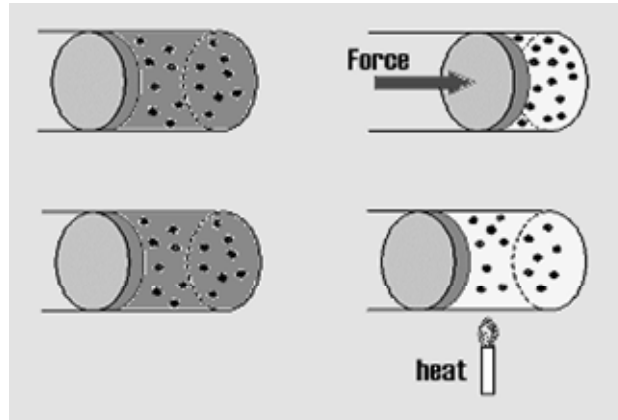


Figure 3-3
Increased Internal Energy Results From Work or Heat

LAWS OF THERMODYNAMICS

The **First Law of Thermodynamics** is the application of the Conservation of Energy principle applied to heat and the thermodynamic process. The change in internal energy in a system is equal to the heat that is added, minus the work performed. When work is performed, the internal energy of a system usually is decreased.

$$\Delta U = Q_{\text{heat added}} - W_{\text{work done}}$$

The **Second Law of Thermodynamics** addresses the efficiency of heat engines and constraints on the direction of heat transfer. It states that it is impossible to extract heat from a warmer reservoir and perform work, without having some of the energy lost to a colder reservoir. Otherwise, it is impossible to have a heat engine that is 100 percent efficient.

Thermal equilibrium is reached when a higher temperature object or system is in contact with a lower temperature system or object. Heat will flow from the warmer system to the colder one, resulting in **thermal equilibrium**. This principle is stated in the **Zeroth Law of Thermodynamics**, which says that if two systems are in thermal equilibrium with a third system, they are in equilibrium with each other.

Activity 3.2

Physics Concepts

Purpose

To review the physical principles related to fire growth.

Directions

1. Work as a group on the Student Activity Worksheet (SAW) provided.
2. After 30 minutes, Group 1 will provide the answer to problem 1, Group 2 to problem 2, and so on.
3. If there are questions about the answers, the group providing the correct answer should work out the problem on the white board.

Activity 3.2 (cont'd)

Worksheet

1. What is the metric volume (m^3) of a room measuring 14 feet x 17 feet, with a 9-foot ceiling?
2. If a room has a temperature of 72 °F, what is the equivalent temperature in degrees Celsius, and Kelvin?
3. List some factors that would need to be considered when analyzing a residential structure to determine if it could be a closed system.
4. Assume the efficiency of a system is equal to the Work done minus (-) the final Temperature. A boiler initially heats a supply loop to 198 °F, and the return water temperature is measured to be 93 °F. What is the efficiency of the supply loop?
5. How many foot pounds of work is done if a 20 kg block of steel is pushed 12 feet?
6. The 14-foot x 17-foot room with a 9-foot ceiling height contains 7 percent carbon dioxide (CO_2) gas by volume. How many liters of CO_2 have been mixed with the room air?
7. A simple beam is supported on two ends by wooden posts. If the 20-foot beam is carrying 12,568 pounds of mass, what is the resisting force applied by one of the supporting end posts? The beam weighs 48 pounds per linear foot.
8. 2.8 kg of water (H_2O) is heated from the ambient room temperature of 20 °C, to 240 °C. How much heat energy (calories) were needed to raise the water to this temperature?
9. A 10-foot x 12-foot room with an 8-foot ceiling contains 1 cubic meter of CO_2 . What is the percentage of CO_2 by volume?
10. One quart of water is heated, raising its temperature 40 °F. How many kcal of heat energy were needed to do this? Assume 1 gallon of water weighs 8.33 pounds.

CONCEPTS OF CHEMISTRY**Moles**

In 1811, Amedeo Avogadro an Italian chemist stated the hypothesis:

Equal volumes of different gases (at the same temperature and pressure) contain equal numbers of particles.

The hypothesis lead to the concept of a **mole** (a counting unit), which is a term derived from the Latin word **moles**, which means "heap" or "pile." A mole (mol) of a pure substance contains Avogadro's number (N_A) of molecules. (6.0221420×10^{23}) This value is defined as the exact number of atoms of pure carbon in 12 grams of carbon (^{12}C). So, if one wanted to determine the mass of one atom of carbon, you would divide 12 grams by Avogadro's number (result: $1.9926465 \times 10^{-23}$). It is far more convenient to work with moles rather than the miniscule mass of an individual atom, a principle reason for the development and use of the concept of moles.

Carbon is the base element for our modern scale of relative atomic masses. The molar mass of one mole (Avogadro's number of atoms) of any element is equal to its atomic number that is obtained from the Periodic Table of Elements. Molar mass is expressed as grams per mole. If we know the mass of a compound, then we can determine the quantity of atoms (moles) present. Refer to this example:

If a sample of CO_2 weighs 29 grams, how many molecules of CO_2 are there?

Relative atomic number for the element carbon (C) is: 12.000
Relative atomic number for the element oxygen (O) is: 15.999
Gram per mole for compound of CO_2 :

$$(1) \bullet (12.000 \text{ g mol}^{-1}[\text{carbon}]) + (2) \bullet (15.999 \text{ g mol}^{-1}[\text{oxygen}])$$

$$(12.000 \text{ g mol}^{-1}[\text{carbon}]) + (31.998 \text{ g mol}^{-1}[\text{oxygen}])$$

$$\text{Total : } 43.998 \text{ g mol}^{-1} (\text{CO}_2 \text{ molecule})$$

$$\frac{\text{dividing known mass of CO}_2 \text{ molecule (29.000 g)}}{\text{molar mass of one (1) CO}_2 \text{ molecule (43.998 g mol}^{-1})}$$

$$= \text{total moles of } CO_2 = \frac{(29.000 \text{ g})}{43.998 \text{ g mol}^{-1}} = .659 \text{ moles of } CO_2$$

$$.659 \text{ moles of } CO_2 \bullet (\text{Avogadro's } 6.0221420 \times 10^{23})$$

$$= \text{number of } CO_2 \text{ molecules in } 29 \text{ g of substance}$$

Chemical Equations

The universe is comprised of millions of substances, all of which can be broken down into basic elements. An element is a substance that cannot be broken down into smaller or simpler substances by ordinary physical or chemical means. The Periodic Table of the Elements currently has 102 natural elements. Scientists also have created numerous other "man-made" elements in recent years, but all other substances on earth are compounds, or combinations, of these basic elements.

Water (H₂O) is a compound, consisting of the elements of hydrogen and oxygen. The water molecule has two hydrogen atoms for every oxygen atom. The "oxidation reaction" (fire) is a process of chemical decomposition. The elements from the chemical decomposition process interact with each other and form by-products of combustion. The process follows the Law of Conservation of Mass:

In every chemical operation an equal quantity of matter exists before and after the operation².

The following chemical equation involves the reaction of 2 molecules of butane with 13 molecules of oxygen. The products of the combustion process are 8 molecules of carbon dioxide and 10 molecules of water. Heat is also given off as a result of the chemical process. We will discuss heat with more detail later in this unit. If one counts the number of atoms of each element, both sides of the equation have the same number of atoms for each element, therefore "...matter existing before and after the operation."

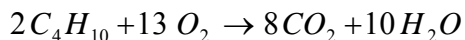


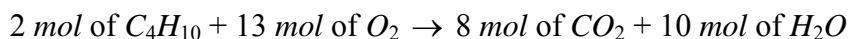
Table 3-3
Periodic Table of the Elements

Element Symbol																					
Atomic Number, Z																					
Atomic Molar mass (g/mol)																					
Electronegativity (Allred-Rochow if Pauling not used.)																					
Valence Configuration																					
Element Name																					
1 1.008 H Hydrogen 1s ¹																	2 4.00 He Helium n.s.				
3 6.941 Li Lithium 2s ¹	4 9.012 Be Beryllium 2s ²															5 10.811 B Boron 2s ² 2p ¹	6 12.011 C Carbon 2s ² 2p ²	7 14.007 N Nitrogen 2s ² 2p ³	8 15.999 O Oxygen 2s ² 2p ⁴	9 18.998 F Fluorine 2s ² 2p ⁵	10 21.18 Ne Neon 2s ² 2p ⁶
11 22.990 Na Sodium 3s ¹	12 24.305 Mg Magnesium 3s ²															13 26.982 Al Aluminum 3s ² 3p ¹	14 28.086 Si Silicon 3s ² 3p ²	15 30.974 P Phosphorus 3s ² 3p ³	16 32.066 S Sulfur 3s ² 3p ⁴	17 35.453 Cl Chlorine 3s ² 3p ⁵	18 39.948 Ar Argon 3s ² 3p ⁶
19 39.098 K Potassium 4s ¹	20 40.078 Ca Calcium 4s ²	21 44.956 Sc Scandium 3d ¹ 4s ²	22 47.88 Ti Titanium 3d ² 4s ²	23 50.942 V Vanadium 3d ³ 4s ²	24 51.996 Cr Chromium 3d ⁵ 4s ¹	25 54.938 Mn Manganese 3d ⁵ 4s ²	26 55.847 Fe Iron 3d ⁶ 4s ²	27 58.933 Co Cobalt 3d ⁷ 4s ²	28 58.69 Ni Nickel 3d ⁸ 4s ²	29 63.546 Cu Copper 3d ¹⁰ 4s ¹	30 65.39 Zn Zinc 3d ¹⁰ 4s ²	31 69.723 Ga Gallium 3d ¹⁰ 4s ² 4p ¹	32 72.61 Ge Germanium 3d ¹⁰ 4s ² 4p ²	33 74.922 As Arsenic 3d ¹⁰ 4s ² 4p ³	34 78.96 Se Selenium 3d ¹⁰ 4s ² 4p ⁴	35 79.904 Br Bromine 3d ¹⁰ 4s ² 4p ⁵	36 83.80 Kr Krypton 3d ¹⁰ 4s ² 4p ⁶				
37 85.468 Rb Rubidium 5s ¹	38 87.62 Sr Strontium 5s ²	39 88.906 Y Yttrium 4d ¹ 5s ²	40 91.224 Zr Zirconium 4d ² 5s ²	41 92.906 Nb Niobium 4d ⁴ 5s ¹	42 95.94 Mo Molybdenum 4d ⁵ 5s ¹	43 98.906 Tc Technetium 4d ⁵ 5s ²	44 101.07 Ru Ruthenium 4d ⁷ 5s ¹	45 102.91 Rh Rhodium 4d ⁸ 5s ¹	46 106.42 Pd Palladium 4d ¹⁰	47 107.87 Ag Silver 4d ¹⁰ 5s ¹	48 112.41 Cd Cadmium 4d ¹⁰ 5s ²	49 114.82 In Indium 4d ¹⁰ 5s ² 5p ¹	50 118.71 Sn Tin 4d ¹⁰ 5s ² 5p ²	51 121.75 Sb Antimony 4d ¹⁰ 5s ² 5p ³	52 127.60 Te Tellurium 4d ¹⁰ 5s ² 5p ⁴	53 126.91 I Iodine 4d ¹⁰ 5s ² 5p ⁵	54 131.29 Xe Xenon 4d ¹⁰ 5s ² 5p ⁶				
55 132.91 Cs Cesium 6s ¹	56 137.33 Ba Barium 6s ²	57 174.97 Lu Lutetium 4f ¹⁴ 5d ¹ 6s ²	58 178.49 Hf Hafnium 4f ¹⁴ 5d ² 6s ²	59 180.95 Ta Tantalum 4f ¹⁴ 5d ³ 6s ²	60 183.85 W Tungsten 4f ¹⁴ 5d ⁴ 6s ²	61 186.21 Re Rhenium 4f ¹⁴ 5d ⁵ 6s ²	62 190.2 Os Osmium 4f ¹⁴ 5d ⁶ 6s ²	63 192.22 Ir Iridium 4f ¹⁴ 5d ⁷ 6s ²	64 195.08 Pt Platinum 4f ¹⁴ 5d ⁹ 6s ¹	65 196.97 Au Gold 4f ¹⁴ 5d ¹⁰ 6s ¹	66 200.59 Hg Mercury 4f ¹⁴ 5d ¹⁰ 6s ²	67 204.38 Tl Thallium 4f ¹⁴ 5d ¹⁰ 6s ² 6p ¹	68 207.2 Pb Lead 4f ¹⁴ 5d ¹⁰ 6s ² 6p ²	69 208.98 Bi Bismuth 4f ¹⁴ 5d ¹⁰ 6s ² 6p ³	70 209 Po Polonium 4f ¹⁴ 5d ¹⁰ 6s ² 6p ⁴	71 210 At Astatine 4f ¹⁴ 5d ¹⁰ 6s ² 6p ⁵	72 222 Rn Radon 4f ¹⁴ 5d ¹⁰ 6s ² 6p ⁶				
87 (223) Fr Francium 7s ¹	88 226.03 Ra Radium 7s ²	103 (260) Lr Lawrencium 5f ¹⁴ 6d ¹ 7s ²	104 (261) Unq Unnilquadium 5f ¹⁴ 6d ² 7s ²	105 (262) Unp Unnilpentium 5f ¹⁴ 6d ³ 7s ²	106 (263) Unh Unnilhexium 5f ¹⁴ 6d ⁴ 7s ²	107 (264) Uns Unnilseptium 5f ¹⁴ 6d ⁵ 7s ²	108 (265) Uno Unniloctium 5f ¹⁴ 6d ⁶ 7s ²	109 (266) Une Unnilennium 5f ¹⁴ 6d ⁷ 7s ²													
57 138.91 La Lanthanum 5d ¹ 6s ²	58 140.12 Ce Cerium 5d ¹ 6s ²	59 140.91 Pr Praseodymium 5d ¹ 6s ²	60 144.24 Nd Neodymium 5d ¹ 6s ²	61 (145) Pm Promethium 5d ⁴ 6s ²	62 150.36 Sm Samarium 5d ¹ 6s ²	63 151.96 Eu Europium 5d ¹ 6s ²	64 157.25 Gd Gadolinium 5d ¹ 6s ²	65 158.93 Tb Terbium 5d ¹ 6s ²	66 162.50 Dy Dysprosium 5d ¹ 6s ²	67 164.93 Ho Holmium 5d ¹ 6s ²	68 167.26 Er Erbium 5d ¹ 6s ²	69 168.93 Tm Thulium 5d ¹ 6s ²	70 173.04 Yb Ytterbium 5d ¹ 6s ²								
89 227.03 Ac Actinium 6d ¹ 7s ²	90 232.04 Th Thorium 6d ² 7s ²	91 231.04 Pa Protactinium 5f ² 6d ¹ 7s ²	92 238.03 U Uranium 5f ³ 6d ¹ 7s ²	93 237.05 Np Neptunium 5f ⁴ 6d ¹ 7s ²	94 (244) Pu Plutonium 5f ⁶ 7s ²	95 (243) Am Americium 5f ⁷ 7s ²	96 (247) Cm Curium 5f ⁷ 7s ²	97 (247) Bk Berkelium 5f ⁹ 7s ²	98 (251) Cf Californium 5f ¹⁰ 7s ²	99 (252) Es Einsteinium 5f ¹¹ 7s ²	100 (257) Fm Fermium 5f ¹² 7s ²	101 (258) Md Mendelevium 5f ¹³ 7s ²	102 (259) No Nobelium 5f ¹⁴ 7s ²								

Stoichiometric Reactions

The study that examines the relationships between the masses of the reaction substances, and the resulting products is called **stoichiometry**. The term is derived from the Greek words *stoicheion*, meaning "element, and *metron* meaning, "measure." The mass of the reactants and products can be determined by using the concept of moles. The actual mass of the reactants needed to satisfy the Law of Conservation can be determined from determining the proportion of moles, and atomic mass of each compound.

Applying the units of moles to the above equation:



Substituting the atomic numbers for each element of the compounds, and calculating the mass in grams: (assuming whole number atomic numbers for carbon: 12; hydrogen: 1; oxygen: 16.

$$C_4H_{10}: [(12 \text{ g mol}^{-1} \bullet 4) + (1 \text{ g mol}^{-1} \bullet 10)] = 58 \text{ g}$$

$$O_2: (16 \text{ g mol}^{-1}) \bullet 2 = 32 \text{ g}$$

$$CO_2: [(12 \text{ g mol}^{-1} \bullet 1) + (16 \text{ g mol}^{-1} \bullet 1)] = 18$$

$$H_2O: [(1 \text{ g mol}^{-1} \bullet 2) + (16 \text{ g mol}^{-1} \bullet 1)] = 18$$

and then multiplying times the number of moles:

$$2 \text{ mol } (58 \text{ g mol}^{-1} C_4H_{10}) + 13 (32 \text{ g mol}^{-1} O_2 \rightarrow$$

$$8 \text{ mol } (44 \text{ g mol}^{-1} CO_2) + 10 \text{ mol } (18 \text{ g mol}^{-1} H_2O)$$

$$116 \text{ g of } C_4H_{10} + 416 \text{ g of } O_2 \rightarrow 352 \text{ g of } CO_2 + 180 \text{ g of } H_2O$$

Comparing the sum of the masses of each side of the equation:

$$532 \text{ g} = 532 \text{ g}$$

THE IDEAL GAS LAW

The Ideal Gas Law may be described as gas in which all collisions between the molecules or atoms are elastic, and there are no internal molecular forces or attractions. The gas molecules of this **ideal gas** are a group of spheres that can collide, but do not react with each other in any other way. All internal energy is in the form of kinetic energy and **changing the kinetic energy** of the gas results in a **change in temperature**. As the gas molecules collide with the sides of the container, a kinetic pressure is created. The Ideal Gas Law infers that the measurement of this pressure, which results from the kinetic activity, is therefore proportional to the temperature.

The three variables that express the state of an ideal gas are all measurable properties. It is inconsequential as to how the gas molecules reach the measured "state." The state of change may be due to the application of either work or heat, as previously noted in the above example. Scientists have established a **standard reference point** (standard temperature and pressure, or STP) relative to expressing and comparing properties and values of ideal gases. The freezing point of water and the standard pressure are expressed below:

1. Pressure (P): standard pressure: 1 atmosphere = 760mmHg=101.3 Kpa.
2. Volume (V): standard volume: 1 mole of ideal gas at STP: 22.4 liters.

3. Temperature (T) (absolute temperature): standard temp.: $0^{\circ}\text{C} = 273.15\text{ K}$.

Typically we measure tire pressure with an air gauge. If we attempt to measure the pressure of a flat tire, the tire pressure gauge would read "zero." This measurement doesn't account for the pressure exerted by the earth's atmosphere. Pressure on a tire gauge equals the **absolute pressure** minus the **atmospheric pressure**. References to the operation of engine carburetors, or our lungs, may state that "negative" pressure occurs. We would state that the proper functioning of the human lungs require a pressure of -4 mmHg, or 4 mmHg below atmospheric pressure.

Ideal Gas Law: $PV = nRT = NkT$

Where: n = number of moles
 R = universal gas constant (8.3145 J/mol K)
 N = number of molecules
 N_A = Avogadro's Number (6.0221420×10^{23})
 k = Boltzmann constant (R/N_A) (1.38066×10^{-23})

Practical form and application of the Ideal Gas Law is stated below. If the temperature is assumed to be constant, then the relationship is stated as **Boyle's Law**. If the pressure is constant, then the derivation may be referred to as **Charles's Law**. This form of the Ideal Gas Law would be appropriate for circumstances occurring under a uniform pressure.

Ideal Gas Law:
$$\frac{P_i V_i}{T_i} = \frac{P_f V_f}{T_f}$$

Boyle's Law: $P_i V_i = P_f V_f$ (constant temperature)

Charles Law: $\frac{V_i}{T_i} = \frac{V_f}{T_f}$ or $V_f = V_i \frac{T_f}{T_i}$ (constant pressure)

Dalton's Law of Partial Pressures was proposed by John Dalton in 1801. He found that for any pure gas, if used the principles of the Ideal Gas Law of ($PV = nRT$), the pressure (P) is directly proportional to the number of moles (n), if the volume (V) and temperature (T) remain the same. So increasing the amount of moles results in an increase in pressure.

Therefore an increase in the vessel's pressure must result from an increase in the amount of matter (number of moles). This principle also holds true if we add another gas to the vessel under consideration. If we have a container of helium and we add an equal number of moles of the gas neon, the pressure will double. This rule would not apply if the gases reacted in

some chemical manner. Each gas of a mixture must act as though the other gas is not present. Dalton's Law of Partial Pressures then states that the sum of the pressures in a mixture of gases is equal to the total pressure. The following equation holds true if we eliminate all of the water vapor from the gases. This must be accomplished either through mechanical means, or through the process of subtraction.

$$P_{\text{total}} = P_1 + P_2 + P_3 + \dots P_n$$

The **Bernoulli Principle** also is a consideration when examining convective flows of gases from a fire. Daniel Bernoulli (1700-1782) was a Swiss mathematician who theorized that as the velocity of a fluid increased, the pressure decreased. The velocity of a gas and its pressure are proportional to their product. When gases reach a point of obstruction, an increase in velocity is required in order to maintain the flow. If the velocity of the gas increases, then the pressure will decrease accordingly. This principle can be applied to the principle of lift with airplane wings.

If we assume the air reaches the rear of the wing at the same time as the air traveling on the underside, then the air that travels over the top of the wing, travels over a longer path, or has greater velocity. Since the air traveling over the top of the wing has greater velocity, then the pressure will be less on the topside of the wing, and the greater pressure from below will create lift or upward "pushing" force. If the Bernoulli Principle is applied to fire gases exiting at a ventilation opening, we should expect an increase in velocity. An increase in temperature inside a closed structure normally will result in an increase in pressure. When the fire gases exit the structure through an opening (such as a window) lower pressure is encountered; therefore according to Bernoulli's Principle, the velocity of the gas should increase. This accounts for observations of fire gases "shooting" out of openings, etc.

PRESSURE CONVERSIONS

Chemistry uses three different expressions to measure pressure. Conversion among the values is necessary in order to use fire dynamic formulas.

$$1.00 \text{ atm} = 760.0 \text{ mm Hg} = 101.325 \text{ kPa} = 101,325 \text{ Pa}$$

Where:

- atm = atmosphere [14.69595 lb_f in², 1.01325 x 10⁵ N/m²];
- mmHg = millimeters of mercury; and
- Pa = Pascals [kPa kilopascal, 1000 Pascals].

THE FIRE TRIANGLE AND FIRE TETRAHEDRON

Combustion (fire) occurs when heat energy decomposes a fuel, which then interacts with an oxidizer, usually atmospheric oxygen. The fire triangle and fire tetrahedron are abstract concepts, which emphasize the dependency that each component of the combustion process has on each another component in order to maintain the reaction.

Fire is defined as: A rapid oxidation process which is a chemical reaction resulting in the evolution of light and heat in varying intensities.

(National Fire Protection Association (NFPA) Standard 921, *Guide for Fire and Explosion Investigations*).

In order for a fire to occur, several conditions must be met:²

1. Combustible fuel must be present and in the exposure range of the heat source.
2. An oxidizer (such as atmospheric oxygen) must be available in sufficient quantity.
3. Energy as a means of ignition (heat) must be applied.
4. The fuel and oxidizer must interact in a self-sustaining chain reaction.

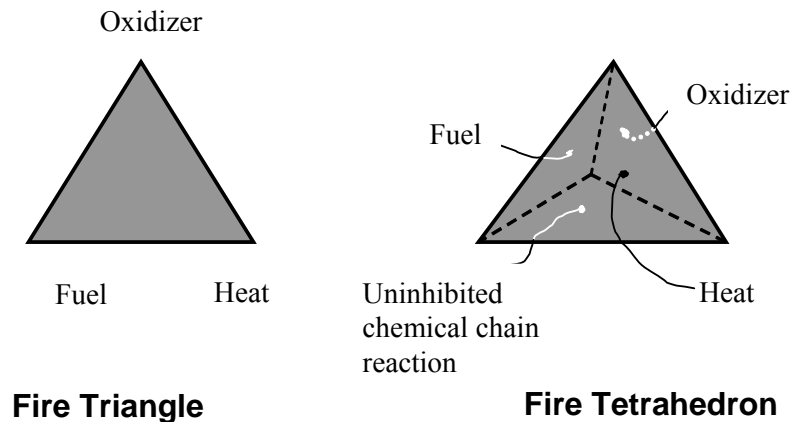


Figure 3-4
Fire Triangle and Fire Tetrahedron

The fire (combustion) process requires the application of a heat source to a combustible fuel (liquid or solids), which decomposes and produces combustible gases. Pyrolysis³ results from the chemical decomposition of a material into one or more other substances by heat alone. The decomposition usually precedes flaming combustion. The process of decomposition results in the production of either flammable or combustible vapors, which then are capable of being ignited by a credible

ignition source. The distance that separates the fuel from the ignition heat source also is critically important. If the fuel(s) and heat energy source are not close enough, the ignition process may stop. The process of fire growth and continuance of the combustion reaction requires that the proportion of oxygen to fuel be within limits dictated by the fuel.

TYPES OF FLAMES

Candle flames are well defined, where the diffusion of the fuel and the oxygen is clearly defined. The laminar flame lacks the turbulence associated with larger fires. Generally, flames higher than 1 foot⁴ will begin to show a greater degree of turbulence. This phenomenon was demonstrated by observation of the rising gases above the candle in the candle exercise at the beginning of the unit. The rising fire plume (fluid flow) of a turbulent flame is unsteady, with unpredictable and erratic behavior. Flames above the height of 1 foot begin to show signs of randomness in both the smoke and flames. Measurement of the temperatures of the flame also are less uniform, due to the movement of the mixing fire gases. Attempts to measure the flame temperature for typical flames will vary from 800 °C to 1,000 °C.⁵

A jet flame results when the fuel supplying the fire is introduced at a high velocity, resulting in flame that is not affected by the effects of buoyancy.

Suppression of fires is accomplished by elimination of one or more of the principle components defined by the fire triangle and tetrahedron. The application of water to suppress the fire is an attempt to lower the temperature and interrupt the uninhibited chemical reaction between the fuel and oxygen. The application of water also results in the production of water vapor or steam. One gallon of water will convert to the equivalent of 1,700 gallons of steam. The expanding water vapor absorbs energy from the fire and its combustion gases, removing the heat component from the fire triangle. The expanding vapor displaces the available oxygen in compartment fires, again removing oxygen from the fire triangle.

PHYSICAL PROPERTIES OF FUELS

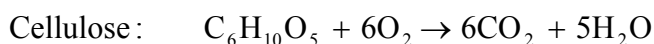
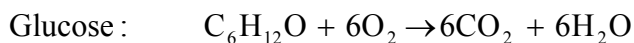
The three states of matter are solids, liquids, and gases. Each of the states of matter has properties that are unique, depending on the nature of the particular material. The combustion process involves chemical decomposition (pyrolysis) of either a solid or liquid. Vapors are the gas form of a liquid or solid after decomposition. Once the material has been pyrolyzed, ignition of the vapors may occur, depending on the combustibility of the vapors and whether a sufficient heat source is present. Common terms associated with ignition properties of various substances:

- **Flashpoint:** Temperature of a liquid fuel at its evaporated state where ignition will occur with an open flame (piloted ignition).
- **Piloted ignition:** A hot spark, flame, or spark that ignites a flammable fuel vapor mixture.
- **Autoignition temperature:** The temperature at which a material will ignite in the absence of an open (piloted) flame. Also referred to as **spontaneous ignition temperature**.
- **Spontaneous combustion:** Combustion occurs as a substance, usually organic, heats up internally as a result of chemical decomposition. (oily rags, wood shavings, hay, etc.)

In fire modeling, we usually are not focused on the initial ignition sequence, assuming that sufficient energy has been applied to a combustible material, which results in combustion to some degree. The combustion can be in the form of either glowing (smoldering) or flaming (diffusion) combustion. We often are questioning ourselves about how the fire spread within a particular compartment. Knowledge of how the various states of material present will interact with the potential energy (heat) created by the fire will assist us in evaluating the best or most appropriate fire-modeling tool to use.

Solids

The majority of fuels that we encounter in fire scenarios are products of decaying vegetable matter in one form or another. They are classified as carbohydrates (base formula: CH_2O), having carbon, hydrogen, and oxygen as the principle elements. Wood and many other wood by-products are composed of cellulose that is a carbohydrate. Cellulose is a series of linked glucose (sugar) molecules and the combustion of cellulose is similar to burning glucose. A comparison of the chemical reactions of glucose and cellulose⁶ follows:



Combustion of wood cellulose is not as efficient as the above chemical reactions indicate, with CO (carbon monoxide) forming due to the lack of oxygen in the fire environment.

The chemical structure of organic fuels is carbon based. Hydrocarbon fuels (gasoline, diesel, etc.) all contain various proportions of carbon and hydrogen, and may be combined with other elements such as oxygen,

nitrogen, and chlorine. The majority of hydrocarbons contain carbon and hydrogen. The most common petroleum (oil) products are known as straight-chain alkanes (*n*-alkanes), examples of which are listed below. They follow the form of:

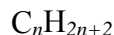


Table 3-4
Typical Hydrocarbons

Name	Formula ⁷
Methane	CH ₄
Ethane	C ₂ H ₆
Propane	C ₃ H ₈
Butane	C ₄ H ₁₀
Pentane	C ₅ H ₁₂
Hexane	C ₆ H ₁₄
Heptane	C ₇ H ₁₆
Octane	C ₈ H ₁₈
Nonane	C ₉ H ₂₀
Decane	C ₁₀ H ₂₂
Pentadecane	C ₁₅ H ₃₂
Triacontane	C ₃₀ H ₆₂

Although solids are one of the principle fuels involved in the burning process, they must be converted to a gaseous vapor state (pyrolysis) prior to combustion occurring. Ignition temperatures of solids generally range from 250 to 450 °C. Autoignition temperatures of solids usually are above 500 °C. Glowing combustion occurs at the surface of the solid material, as oxygen chemically interacts with decomposed fuel. The temperature of glowing combustion usually are above 1,000 °C. Solid materials do not have values for flashpoints or flammable limits.

The terms below are useful in describing properties concerning solid fuel combustion.

- **Density (ρ):** The density of a solid is a measure of the mass of the substance divided by the volume. Usually expressed as kg/m³.
- **Thermal conductivity (k):** The thermal conductivity, ability to absorb and transmit heat energy is expressed as W/m-K.

- **Specific heat (c):** Measurement of a substance's ability to store heat energy. It is a measure of the amount of energy required to raise the temperature of 1 kg, 1 degree Celsius. The value for specific heat is expressed as J/kg-K (or J/mol-K).
- **Thermal diffusivity (α):** The thermal diffusivity (small case alpha) is a relationship of the product of a materials density and conductivity, divided by the specific heat value. Expressed as $k/\rho c$.
- **Thermal resistance (R-value):** A material's R-value is used to make comparable analysis of its ability to restrict heat flow. The higher the R-value, the greater the ability of the material to resist heat flow. The R-value is the **reciprocal** of kA/L .
- **Thermal inertia ($k\rho c$):** An expression of the combination of a material's density (ρ), heat capacity(c), and thermal conductivity (k). Substances with higher values of inertia require a greater quantity of energy in order to reach their ignition temperature. Values for thermal inertia are expressed as $(kW/m^2-K) s^2$.
- **Heat of gasification (L):** is defined as the amount of energy required to convert a solid (or liquid) material to a gaseous combustible state. The energy is expressed in kJ/kg. Gasification values for solids are approximates, because solids are undergoing glowing combustion, attain their peak heat release rate early, and then gradually decline. Glowing combustion (smoldering) often remains during the decay portion of fire development, but could be responsible for ignition during the incipient phase.
- **Heat of fusion:** Energy (heat) expressed in calories, required to convert 1 gram of a material from a solid to a liquid state. (Example: ice to water)

Liquids

Combustion of a liquid fuel occurs when vapors (gaseous phase of liquid) forming above the surface of the liquid mix with air, and come into contact with a sufficient ignition source. Ignition of fuels in the liquid vapor state generally ignite with less energy and time than solid fuels. The following properties and terms assist us in describing the properties of various liquid fuels themselves, with properties of vapors discussed with gases.

- **Boiling points:** A temperature at which a liquid changes to a gas phase. The temperature value varies with pressure.
- **Flashpoint:** Temperature of a liquid fuel at its evaporated state, where ignition will occur with an open flame (piloted ignition).
- **Specific gravity:** A comparison of the mass of a liquid to an equal volume of water (water having a value of 1). The value specifies whether a liquid will float or sink in water.
- **Evaporation:** The rate of evaporation of a liquid is dependent upon the temperature of the liquid (boiling water versus standing water in room air).
- **Heat of vaporization (L):** The amount of energy required to convert a liquid to a gaseous or vapor state. The energy is expressed in kJ/kg

Gases

Flammable gases and vapors are available for combustion if they are within the flammable range for the particular fuel. The supply of oxygen, and a credible ignition source must be present for combustion to occur. Gases and vapors that have been sufficiently "mixed" with oxygen are said to be premixed fuels, having the proper proportioning, which will result in ignition upon contact with an ignition source. The blue flame at the lower portion of the candle is an example of a premixed flame, with little soot, in contrast to the upper yellow to white color associated with the soot-burning region.

- **Vapor pressure:** If we assume that a liquid is contained within a closed system, evaporation will take place above the liquid, until equilibrium is attained. A saturated evaporation state is reached when the liquid no longer permits evaporation. The pressure exerted on the liquid by the vapors is measured in mmHg.
- **Vapor density:** A value describing the average molecular weight of a gas or vapor, when compared to the same volume of oxygen (which is assigned a value of 1). If the vapor density of a gas is >1 , the gas or vapor (Example: gasoline) will fall or sink in an oxygen atmosphere. If < 1 , the gas will rise (Example: helium).

- **Fuel/Air ratio:** The potential to ignite various concentrations of flammable gases and atmospheric oxygen is a function of their proportioning, expressed as a percentage. Research has defined the upper (UFL) and lower (LFL) limits for common gases. The percentage of fuel vapors to oxygen permits us to determine ignition sequences and mass loss rate of the fuel in order to obtain combustion.
- **Lower flammable limit (LFL):** Concentrations of the fuel-air mixture below the LFL will be too lean, and not support ignition of the vapors. Also may be expressed as the lower explosive limit (LEL).
- **Upper flammable limit (UFL):** Concentrations above the UFL will not ignite because the fuel-air mixture is too rich. Also expressed as upper explosive limit (UEL).

OXYGEN

The oxygen content of the atmosphere is approximately 20.9 percent, with the remainder principally comprised of nitrogen. Fire atmospheres lacking oxygen will affect the rates of combustion of the targeted fuels.

Scientific research has determined that there is a correlation between the amount of oxygen consumed in a fire and the typical energy released for commonly encountered fuels. Exhaust gases from a test fire are monitored by an **oxygen consumption calorimeter**, and a determination of the amount of oxygen that is consumed during the process is derived. Data obtained from burning different materials have resulted in an approximate constant value as to the amount of energy that typically is produced during the combustion of a wide range of common fuel items. On average 13 mega-Joules of energy is released per kilogram of oxygen consumed (13.1 MJ/kg).

METHODS OF HEAT TRANSFER

Conduction and **radiation** are the two primary methods of heat transfer. Conduction occurs when a solid is exposed to a source of heat and the energy is transmitted or travels across the object. **Convection** is the principle means of heat transfer in fire situations, and actually is a secondary means of conduction. Heated atmospheric air passes over objects, and this interaction permits heat transfer by direct contact between the hot air (or liquid) and the involved surface. Radioactive heat from the passing particles in the hot air stream (fluid flow) also transfers heat

energy to the target surface in a convective flow. Hot objects (flaming combustion) emit infrared radiation, which pass through air and raises the surface temperature of line-of-sight objects.

The three methods of heat transfer can be observed in the dynamics of a candle flame. Conduction can be demonstrated by holding the base of the spoon in the candle flame for a short period of time, and feel the heat being conducted along the shaft. If we hold a spoon 1 centimeter away from the candle for 20 seconds, heat must be transmitted to the spoon through the atmosphere by radiation. Holding an open hand approximately 1 foot above the burning candle also results in a sensation of heat, as the path or flow of rising warm air (thermal column or fire plume) is interrupted.

Heat Transfer and Ignition

Ignition of a particular fuel source is dependant upon the following conditions⁸. We will assume that the heat and fuel are being brought into contact with each other in an atmospheric air that readily supports combustion.

1. The **ignition source** must have sufficient energy to ignite the target fuel.
2. The presence of a **fuel** within the flammability range.
3. **Contact** between a credible ignition sources while the fuel its flammability limits.
4. Duration of contact between a credible ignition source and a fuel in order to have exchange of sufficient energy, in order to result in an ignition of the fuel.

Conduction

When energy is passed along a substance by **conduction**, the atoms of the substance have increased energy in proportion to the degree of heat transfer. The energy from the transferred heat results in a higher level of vibration between the affected atoms. The energy then is transferred along the substance as each molecule receives a portion of the heat energy from its neighboring atoms. The rate of heat transfer through a substance is dependent on the dimensions involved. In solids, the degree and rate of heat transfer will be dependant upon the length, and cross-section of the

material involved. In liquids or gases, the volume or mass will be a primary factor involved with the rate of heat transfer.

Joseph Fourier (1768-1830) was employed by and traveled to Egypt with Napoleon's army on an expedition. During this period, Fourier made many observations about heat transfer, which he later published in *Memoire sur la Chaleur*. He determined that the rate of heat conduction was dependent upon or regulated by temperature differences, and that heat would always travel from an area of higher temperatures to an area of lower temperatures.

The rate at which heat will travel through a material is expressed as it's **thermal conductivity**, represented by the small letter **k**. Thermal conductivity is expressed in units of W/m.K or W/m² in either Kelvin or degrees Celsius. The relationship of heat transfer⁹ and temperature differences is expressed as:

$$\dot{q} = \frac{kA(T_2 - T_1)}{l},$$

isolating for value of "k"

$$k = \frac{\dot{q}l}{A(T_2 - T_1)}$$

Where : \dot{q} = rate of heat conduction (kW [or kJ / s])

k = thermal conductivity (W / m [or m²])

$T_2 - T_1$ = temperature difference (°C or K)

l = length of heat travel

A = cross - section of conduction or exposure

Understanding the possible role of conduction in examination of fire-spread scenarios is important to the investigator, due to the need to understand possible ignition scenarios, or eliminate potential multiple points of origin. Areas of multiple fires actually can result from heat transfer by conduction through mediums such as metal pipes, or convection transportation of superheated air. Developing estimates of potential heat release rates and temperature that are possible during a fire examination can help in determining what role conduction played in the fire spread.

Convection

Convection results when either liquids or gases are exposed to heat, which also causes expansion of the substance. The expansion results in a lower density (kg/L) than the surrounding medium and, due to the Archimedes Principle, the warmer gases or liquids rise. Heat transfer occurs when the convective flow (fire plume) passes over or is in contact with a solid surface. This interaction results in heat being transmitted by direct contact, which then is transferred through the solid surface by conduction.

Fire pattern analysis is based on the surface effects and patterns that result from hot fire traveling over and across their surfaces. Convection is one of the primary means of heat transfer for fires within structures, particularly in the earlier stages of fire growth. "V"-patterns, "U"-patterns, truncated cone patterns, and references to "lines of demarcation" all result from convective forces within the fire compartment. The heated gases from the combustion process rise above the burning material and travel to points of escape, or build-up at ceiling level and begin "pushing" downwards. In the former case, it would be expected that the pressure in the fire compartment would rise, since the expanded gases have nowhere to vent.

The Archimedes Principle states that an object submersed in a fluid (liquid or gases) is buoyed-up (pushed-up) by a force equal to the mass of the displaced fluid. In determining if a substance will rise or fall, the density (weight and volume) of the substance must be compared to the surrounding medium (either gas or liquid). If the density is less, than the substance or object will rise, (or float if the surrounding medium is a liquid). Conversely, substances that have a higher density will fall or sink as applicable.

Convective heat transfer results from differences of temperature when a liquid or gas (fluid flow) comes into contact with a surface (usually a solid). Re-arranging the formula for thermal conductivity produces the below formula, which can provide us with a heat flux on a surface (wall, ceiling, occupant, etc.) which is imposed from a fluid flow (liquid or gas).

$$\dot{q}'' = h(T_2 - T_1)$$

Where: $\dot{q}'' = \dot{q} / A$ = heat flux or heat flow rate per unit area (kW / m^2)

$T_2 - T_1$ = fluid and surface temperature differences ($^{\circ}C$ or K)

Convective heat transfer coefficient

$$\text{value of } (h) = \frac{k}{l}$$

k = thermal conductivity ($W / m[or m^2]$)

l = length of heat travel

The symbol h represents the convective heat transfer coefficient, or k/l . The value of h is difficult to determine, since it requires knowledge of both the fluid properties and velocity of the convective gases or liquids. Typical values for h are available from research data and should not differ greatly under typical fire conditions. The convective heat transfer coefficient for most turbulent fires should be in the range of 5 to 10 kW/m^2 .¹⁰

Table 3-5
Values for the Convective Coefficient (h)¹¹

Fluid Condition	h (W/m ² -°C)
Buoyant flows in air	5 – 10
Laminar match flame	~ 30
Surface of turbulent liquid pool fire	~ 20
Fire plume impinging on a ceiling	5 – 50
2 m/s wind speed in air	~ 10
35 m/s wind speed in air	~ 75

Radiation

Max Planck (1858-1947), a German physicist, developed revolutionary theories in physics, including radiation heat transfer. His theory states that radiation is electromagnetic energy. The radiation energy has wavelength and travels at the speed of light in a vacuum. All objects having temperatures above absolute zero emit thermal radiation. Thermal radiation will appear to be bright red in color when an object's surface temperature is above 1,000 °C. The majority of thermal radiation occurs in the infrared frequency range and is not visible to the human eye. "Night vision" technology detects the infrared thermal radiation spectrum, permitting us to see in the dark.

Thermal radiation becomes the principle means of heat transfer in large-scale fires. Radiation is emitted during the growth of a fire and is absorbed and re-emitted by all surfaces within a room and by soot and other fire gases. For many years, the significance of thermal radiation was not understood. Most of the fire data was collected in bench-scale

experiments, primarily due to the difficulty of conducting large-scale test fires. "It is now recognized that radiation is the dominant mode of heat transfer in flames with characteristic lengths exceeding 0.2 m, while convection is more significant in smaller flames."¹² Water and carbon dioxide (CO₂) are prevalent in combustion gases and are effective absorbers and emitters for a significant portion of the thermal radiation spectrum. Many of the combustion products of hydrocarbon fuels are good absorbers of radiation, and soot is a strong emitter of radiation.

Common effects of thermal radiation, which we could expect under normal fire conditions, are listed below:

Table 3-6
Common Effects of Thermal Radiation

Radiant Heat Flux (q) [kW/m²]	Effect¹³
1.0	Direct summer sun
6.4	Pain after 8 seconds of skin exposure
16	Blistering of skin in 5 seconds
12.5	Piloted ignition of wood after prolonged exposure
20	Some cellulose materials ignite
29	Wood ignites spontaneously after prolonged exposure
52	Fiberboard ignites in 5 seconds
100 - 150	Postflashover conditions

Max Planck's formula for radiation is based upon the concept of a perfect radiator, or blackbody. The theoretical blackbody absorbs all radiation which it is exposed to and re-radiates the energy. The maximum possible amount of radiation possible due to the temperature is expressed as:

$$\dot{q}'' = \sigma T^4$$

Where:

\dot{q}'' = **heat flux**

ϵ (*epsilon*) = emissivity

σ (*sigma*) = $5.67 \times 10^{-11} \text{ kW} / \text{m}^2 - \text{K}^4$ Stefan – Boltzman constant

T_2 = temperature of emitter expressed in Kelvin (*K*)

F_{12} = configuration factor

The formula indicates that for every doubling of the temperature in Kelvin, the heat flux will increase by a factor of 16. Real-world fire environments do not permit conditions of perfect absorption and emission of radiation. Emissivity is a fractional value that is typically between 0.8 ± 0.2 for solids or liquids. The depth of flame and the interaction of products of combustion affect Emissivity for flames and gases. The emissivity for flames can be estimated by the formula below formula. The absorption coefficient is an expression dealing with how readily a flame can be penetrated by radiation. Turbulent fires will normally have a k factor of 0.1 to 1.0 m^{-1} (with 1.0 m^{-1} being typical of fires with flames thicker than 2 meters.) Larger fires may produce significant amounts of soot that will obscure the flame and reduces the heat flux value.¹⁴

$$\varepsilon = 1 - \exp(-kl)$$

Where: ε (epsilon) = emissivity
 k = absorption coefficient
 l = flame thickness

Determining what the potential heat flux will be on objects in the line-of-sight of a radiant heat source is a useful tool for the field investigator. Calculating for heat flux can help in determining if a witness or occupant should of received thermal radiation burns, or to eliminate radiant heat flux as a possible cause for what appears to be multiple points of origin. There are two derivations of the formula for determining the potential heat flux imposed on an object from a point source, such as a flame, depending on the fire conditions, and distance away from the radiant heat source. F_{12} represents a *configuration factor*, which is a relational fraction of the total view of the target object, which is occupied by the heat flux-emitting surface. The fraction requires determination of the height and width of the emitter, and then each dimension is divided by the distance to the target fuel. The resulting quotients are used to determine what are the established values for configuration factors. The heat flux formula using the configuration factor and emissivity variable is complex and involves many steps in order to derive a heat flux value. This formula will be useful for determining heat flux in conditions where either the target fuel is close to the emitter, or the radiant body is large.

$$\dot{q}'' = \varepsilon \sigma T^4 F_{12}$$

Where: $\dot{q}'' = \varepsilon \sigma T^4 F_{12}$
 ε (epsilon) = emissivity
 σ (sigma) = $5.67 \times 10^{-11} \text{ kW/m}^2 \cdot \text{K}^4$ Stefan - Boltzman constant
 T^2 = temp. of emitter expressed in Kelvin (K)
 F_{12} = configuration factor

The below formula does not involve the complexity of the above one, and produces similar results when the target object is more than 2 diameters away from the burning fuel. The fire under consideration should be considered a point source of heat flux. Examination of the formula reveals that as the distance of the target object is doubled, the heat flux will diminish to one-quarter of the previous value. The denominator of the fraction is the formula for determining the area of a sphere; therefore as the radius (distance from emitting source) is increased, the denominator (area of sphere) increases and reduces the value of the heat flux value in the numerator. Typical values for the constant X_r would vary from 0.15 for fuels which have less soot (methane) and 0.60 for fuels producing large amounts of soot (polystyrene)¹⁵.

Table 3-7
Typical Radioactive Energy Fractions (X_r)

Distance Greater than 0.5 Meters ¹⁶	
Methanol, methane	.15 - .20
Butane, benzene, wood cribs	.20 - .40
Hexane, gasoline, polystyrene	.40 - .60

The formula below will be used for our study of heat flux during this course.

$$\dot{q}'' = \frac{X_r \dot{Q}}{4\pi c^2}$$

Where: \dot{q}'' = heat flux
 X_r = fraction of energy released relative to the total energy released
 \dot{Q} = energy release rate of fire (kW)
 π (pi) = 3.1416...ratio (circumference of circle ÷ diameter)
 c = radius from emitter to target object

MEASUREMENT OF FIRE CONDITIONS

Materials undergo changes when subjected to heat, principally losing mass and releasing energy during the combustion process. The below terms will be useful in attempting to quantify heat or energy release rates.

- **Mass loss rate** (kg/s or g/s): The mass loss rate or "burning rate" of a material is determined from weighing a material while it is undergoing chemical decomposition through combustion. The rate of loss(\dot{m}) is expressed as mass of fuel being consumed per unit of time, (kg/s or g/s).
- **Mass burning flux** (\dot{m}''): Mass flux is an expression of a materials burning rate per unit area, expressed as kg/(m²-s)
- **Heat of combustion**(ΔH_c): The effective heat of combustion of a material is a measurement of the chemical energy released during the vaporization of a substance. It is expressed as kilo Joules per gram of material.

The terms and concepts listed below help to explain or quantify the interaction of fire with various materials and the confines of the involved compartment. Fire models use the values to predict outcomes, based on the input data that has been obtained from the fire scene and applicable research material. Refer to formulas for determining heat flux from radiation and convective flows. Thermal conductivity was covered in the Methods of Heat Transfer section of this text.

Flame Height

$$H_f = 0.174(k\dot{Q}_{(kw)})^{0.4}$$

H_f = height of flame in meters (m)

Where : k = factor of 1 when there are no nearby walls

k = factor of 2 when the fuel package is near a wall

k = factor of 4 when the fuel package is in a corner

\dot{Q} = heat release rate of fuel expressed in kiloWatts (kW)

Heat Release Rate

$$\dot{Q} = \frac{79.18 H_f^{5/2}}{k}$$

\dot{Q} = heat release rate of fuel expressed in kiloWatts (kW)
 k = refer to the values provided in above flame height formula
 H_f = flame height in metres (m)

Lateral or Downward Flame Spread¹⁷

$$V = \frac{\dot{q}''}{\rho c_p A (T_{ig} - T_s)^2} \text{ or } \frac{\phi}{k \rho c_p (T_{ig} - T_s)^2}$$

Where: V = lateral velocity of flame spread (m/s)

A = cross-sectional area affected by the heating of \dot{q}''

ϕ = (phi) ignition factor from flame spread data
 (kW² / m²) ASTM E 1321-97a (2002)

k = thermal conductivity (W/m-K)

ρ = density (kg/m³)

c_p = specific heat capacity (kJ/kg-K)

T_{ig} = piloted fuel ignition temperature (°C)

T_s = unignited ambient air temperature (°C)

Ignition Time for Thermally Thick and Thin Materials¹⁸

Thermally thin
$$t_{ig} = \rho c l_p \left(\frac{T_{ig} - T_{\infty}}{\dot{q}''} \right)$$

Thermally thick
$$t_{ig} = \frac{\pi}{4} k \rho c_p \left(\frac{T_{ig} - T_{\infty}}{\dot{q}''} \right)^2$$

Where: t_{ig} = time to ignition in seconds
 k = Thermal conductivity (W/m-K)
 ρ = density (kg/m³)
 c_p = specific heat capacity (kJ/kg-K)
 l = thickness of material (mm)
 T_{ig} = piloted fuel ignition temperature
 T_{∞} = initial temperature
 \dot{q}'' = radiant heat flux (kW/m²)

Convective Heat Flux

$$\dot{q}'' = h(T_2 - T_1)$$

Where: $\dot{q}'' = \dot{q} / A$ = heat flux or heat flow rate per unit area (kW/m²)
 $T_2 - T_1$ = fluid and surface temperature differences (°C or K)

Convective heat transfer coefficient

$$\text{value of } (h) = \frac{k}{l}$$

k = thermal conductivity (W/m [or m²])

l = length of heat travel

Radiant Heat Flux

$$\dot{q} = \frac{kA(T_2 - T_1)}{l}$$

isolating for value of "k"

$$k = \frac{\dot{q}}{A(T_2 - T_1)}$$

Where: \dot{q} = rate of heat conduction (kW [kJ/s])
 k = thermal conductivity (W/m [or m²])
 $T_2 - T_1$ = temperature difference (°C or K)
 l = length of heat travel
 A = cross-section of conduction or exposure

Heat Release Rate and Flashover

$$HRR_{fo} (kW) = (750A_o)(h_o)^{0.5}$$

Where: HRR = Heat Release Rate for flashover in kiloWatts (kW)

A_o = area of opening in square meters (m²)

h_o = height of opening in meters

Thomas flashover correlation:

$$\dot{Q}_{fo} = (378A_o) \sqrt{h_o} + 7.8A_w$$

Where: \dot{Q}_{fo} = Heat Release Rate for flashover in kiloWatts (kW)

A_o = area of opening in square meters (m²)

h_o = height of opening in meters

A_w = area of walls, ceiling, and floor (minus opening)

Activity 3.3

Chemistry Concepts

Purpose

To review physical principles related to fire growth.

Directions

1. Work as a group on the following Worksheet.
2. After 30 minutes, Group 1 will provide the answer to problem 1, Group 2 to problem 2, and so on.
3. If there are questions about the answers, the group providing the correct answer should work out the problem on the white board.

Activity 3.3 (cont'd)**Chemistry Concepts Worksheet**

Note: For these problems, assume the following:

- Carbon: molar mass of 12 grams;
 - Oxygen: molar mass of 16 grams;
 - Hydrogen: molar mass of 1 gram;
 - Ideal Gas Law: 1 mole of ideal gas is 22.4 liters;
 - 13.1 MJ of energy is released per kg of oxygen; and
 - refer to the conversion charts in Appendix B for all other conversion factors.
1. Balance this combustion reaction, which depicts combustion of methane (CH_4).
 2. Balance this combustion reaction, which depicts combustion of propane (C_3H_8).
 3. Create and balance a reaction for burning wood (cellulose). Assume the chemical composition of wood to be $\text{C}_6\text{H}_{10}\text{O}_5$.
 4. Balance this combustion reaction, which depicts combustion of methanol (CH_3OH).
 5. How many moles of oxygen are needed to consume 20 moles of propane? (C_3H_8)

In Problem 12 we learned that 5 moles of O_2 are needed to in the combustion reaction of 1 mole of C_3H_8 .
 6. What is the mass of oxygen, carbon dioxide, and water involved in the combustion of methanol?
 7. What is the mass of oxygen (in grams) that would be needed to completely consume 158 pounds of wood? Use dimensional analysis to solve the problem.
 8. How much energy could we reasonably estimate to be released from combustion of the 158 pounds of wood?
 9. What is the heat release rate if we burn 158 pounds of wood in 60 seconds?
 10. What is the percent volume by weight, of carbon dioxide, if the 158 pounds of wood were consumed in the combustion process in a 10' x 12' room with an 8' ceiling height?

SUMMARY

Theories of fire development are based upon the scientific principles and the fundamental laws discussed in this unit. The science-based study of fire has led to the creation of a multitude of fire models that interpret the potential actions of heat and other products of combustion. By having a better understanding of the fundamental principles discussed in this unit, students will be equipped with "science-based" tools that will aid both in the identification of relevant data, and in the analysis of fire spread.

Activity 3.4

Summary of Dynamics of Candle Flame

Purpose

To review the mechanics of fire growth and relate those principles to the candle.

Directions

1. This assignment is due in the morning.
2. Your work will be corrected and handed back to you the next day.

Scenario

Assume that you are testifying about a fire in a court of law, and the judge asks you to explain terminology you have referenced relative to the combustion process. You request permission to use a candle in order to demonstrate the principles you have referenced, and are permitted to do so.

Assuming you have lighted a candle, summarize the combustion of a candle by **listing no more** than ten points.

Describe: the combustion of fuel; methods of heat transfer; difference between temperature and heat; effects of buoyancy and air entrainment; and any other points of interest.

Limit each talking point to a maximum of several sentences. Your courtroom testimony should be concise and to the point, enhancing your credibility as an expert witness.

ENDNOTES

- ¹ Quintere, James G. *Principles of Fire Behavior*. Delmar Publishers, 1998, p. 25.
- ² DeHaan, John D. *Kirk's Fire Investigation*. 5th ed. Prentice Hall, 2002, p. 21.
- ³ NFPA 921, *Guide for Fire and Explosion Investigations*. 2001 ed. p. 921-9.
- ⁴ Quintere, p. 26.
- ⁵ Quintere, p. 37.
- ⁶ DeHaan, p. 16.
- ⁷ Oxtoby, Gillis, Nachtrieb. *Principles of Modern Chemistry*. 5th ed. Thomson Learning, 2002, p. 715.
- ⁸ DeHaan, p. 62.
- ⁹ DeHaan, p. 34
- ¹⁰ Quintere, p. 54-55.
- ¹¹ Quintere, Table 3-2, p. 54
- ¹² Lee, K.Y., Tien, C.L., and Stretton, A.J. *Radiation Heat Transfer*, SFPE Handbook, 1990, p. 1-92.
- ¹³ Drysdale, D.D. *An Introduction to Fire Dynamics*. 2nd ed., John Wiley & Sons, Chichester, U.K., 1997, p. 61.
- ¹⁴ Quintere, p. 55.
- ¹⁵ Quintere, p. 58.
- ¹⁶ Quintere, Table 3-3, p. 239.
- ¹⁷ Quintere, p. 88.
- ¹⁸ DeHaan, John D., Icove, Dave J. *Forensic Fire Scene Reconstruction*. Pearson/Prentice, Hall, 2004, p. 54.

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APPENDIX A

The Chemical History of a Candle, Faraday's Christmas Lectures, 1860, Michael Faraday.

The Chemical History of a Candle

Faraday's Christmas Lectures, 1860

In 1826 Michael Faraday inaugurated the Christmas Lectures for young people at the Royal Institution, Albemarle St, London. Apart from a few, the delivery of which was prevented by WWII, the lectures have been running ever since. One of the most famous of these lectures was on The Chemical History of a Candle, given by Faraday in 1860. Actually a series of six talks, the breadth of interest and the variety of observations and phenomena which Faraday brings in to the subject remain astonishing a century and a half later. The note-taking was by (Sir) William Crookes, co-discoverer of the element Thallium.

Lecture 1: a candle flame

I purpose, in return for the honour you do us by coming to see what are our proceedings here, to bring before you, in the course of these lectures, the Chemical History of a Candle. I have taken this subject on a former occasion, and, were it left to my own will, I should prefer to repeat it almost every year, so abundant is the interest that attaches itself to the subject, so wonderful are the varieties of outlet which it offers into the various departments of philosophy. There is not a law under which any part of this universe is governed which does not come into play and is touched upon in these phenomena. There is no better, there is no more open door by which you can enter into the study of natural philosophy than by considering the physical phenomena of a candle. I trust, therefore, I shall not disappoint you in choosing this for my subject rather than any newer topic, which could not be better, were it even so good. And, before proceeding, let me say this also: that, though our subject be so great, and our intention that of treating it honestly, seriously, and philosophically, yet I mean to pass away from all those who are seniors among us. I claim the privilege of speaking to juveniles as a juvenile myself. I have done so on former occasions, and, if you please, I shall do so again. And, though I stand here with the knowledge of having the words I utter given to the world, yet that shall not deter me from speaking in the same familiar way to those whom I esteem nearest to me on this occasion.

And now, my boys and girls, I must first tell you of what candles are made. Some are great curiosities. I have here some bits of timber, branches of trees particularly famous for their burning. And here you see a piece of that very curious substance, taken out of some of the bogs in Ireland, called candle-wood; a hard, strong, excellent wood, evidently fitted for good work as a register of force, and yet, withal, burning so well that where it is found they make splinters of it, and torches, since it burns like a candle, and gives a very good light indeed. And in this wood we have one of the most beautiful illustrations of the general nature of a candle that I can possibly give. The fuel provided, the means of bringing that fuel to the place of chemical action, the regular and gradual supply of air to that place of action - heat and light - all produced by a little piece of wood of this kind, forming, in fact, a natural candle.

But we must speak of candles as they are in commerce. Here are a couple of candles commonly called dips. They are made of lengths of cotton cut off, hung up by a loop, dipped into melted tallow, taken out again and cooled, then re-dipped, until there is an accumulation of tallow round the cotton. In order that you may have an idea of the various characters of these candles, you see these which I hold in my hand - they are very small and very curious. They are, or were, the candles used by the miners in coal mines. In olden times the miner had to find his own candles, and it was supposed that a small candle would not so soon set fire to the fire-damp¹ in the coal mines as a large one; and for that reason, as well as for economy's sake, he had candles made of this sort - 20, 30, 40, or 60 to the pound. They have been replaced since then by the steel-mill, and then by the Davy lamp, and other safety lamps of various kinds. I have here a candle that was taken out of the Royal George², it is said, by Colonel Pasley. It has been sunk in the sea

for many years, subject to the action of salt water. It shows you how well candles may be preserved; for, though it is cracked about and broken a great deal, yet when lighted it goes on burning regularly, and the tallow resumes its natural condition as soon as it is fused.

Mr. Field, of Lambeth, has supplied me abundantly with beautiful illustrations of the candle and its materials; I shall therefore now refer to them. And, first, there is the suet - the fat of the ox - Russian tallow, I believe, employed in the manufacture of these dips, which Gay-Lussac, or some one who intrusted him with his knowledge, converted into that beautiful substance, stearin, which you see lying beside it. A candle, you know, is not now a greasy thing like an ordinary tallow candle, but a clean thing, and you may almost scrape off and pulverize the drops which fall from it without soiling any thing.

This is the process he adopted ³: The fat or tallow is first boiled with quick-lime, and made into a soap, and then the soap is decomposed by sulphuric acid, which takes away the lime, and leaves the fat rearranged as stearic acid, while a quantity of glycerine is produced at the same time. Glycerine - absolutely a sugar, or a substance similar to sugar⁴ comes out of the tallow in this chemical change. The oil is then pressed out of it; and you see here this series of pressed cakes, showing how beautifully the impurities are carried out by the oily part as the pressure goes on increasing, and at last you have left that substance, which is melted, and cast into candles as here represented. The candle I have in my hand is a stearin candle, made of stearin from tallow in the way I have told you. Then here is a sperm candle, which comes from the purified oil of the spermaceti whale. Here, also, are yellow beeswax and refined beeswax, from which candles are made. Here, too, is that curious substance called paraffine, and some paraffine candles, made of paraffine obtained from the bogs of Ireland. I have here also a substance brought from Japan since we have forced an entrance into that out-of-the-way place - a sort of wax which a kind friend has sent me, and which forms a new material for the manufacture of candles.

And how are these candles made? I have told you about dips, and I will show you how moulds are made. Let us imagine any of these candles to be made of materials which can be cast. "Cast!" you say. "Why, a candle is a thing that melts, and surely if you can melt it you can cast it." Not so. It is wonderful, in the progress of manufacture, and in the consideration of the means best fitted to produce the required result, how things turn up which one would not expect beforehand. Candles can not always be cast. A wax candle can never be cast. It is made by a particular process which I can illustrate in a minute or two, but I must not spend much time on it. Wax is a thing which, burning so well, and melting so easily in a candle, can not be cast. However, let us take a material that can be cast. Here is a frame, with a number of moulds fastened in it. The first thing to be done is to put a wick through them. Here is one - a plaited wick, which does not require snuffing supported by a little wire. It goes to the bottom, where it is pegged in - the little peg holding the cotton tight, and stopping the aperture so that nothing fluid shall run out. At the upper part there is a little bar placed across, which stretches the cotton and holds it in the mould. The tallow is then melted, and the moulds are filled. After a certain time, when the moulds are cool, the excess of tallow is poured off at one corner, and then

cleaned off altogether, and the ends of the wick cut away. The candles alone then remain in the mould, and you have only to upset them, as I am doing, when out they tumble, for the candles are made in the form of cones, being narrower at the top than at the bottom: so that, what with their form and their own shrinking, they only need a little shaking, and out they fall. In the same way are made these candles of stearin and of paraffine. It is a curious thing to see how wax candles are made. A lot of cottons are hung upon frames, as you see here, and covered with metal tags at the ends to keep the wax from covering the cotton in those places. These are carried to a heater, where the wax is melted. As you see, the frames can turn round; and, as they turn, a man takes a vessel of wax and pours it first down one, and then the next, and the next, and so on. When he has gone once round, if it is sufficiently cool, he gives the first a second coat, and so on until they are all of the required thickness. When they have been thus clothed, or fed, or made up to that thickness, they are taken off and placed elsewhere. I have here, by the kindness of Mr. Field, several specimens of these candles. Here is one only half-finished. They are then taken down and well rolled upon a fine stone slab, and the conical top is moulded by properly shaped tubes, and the bottoms cut off and trimmed. This is done so beautifully that they can make candles in this way weighing exactly four or six to the pound, or any number they please.

We must not, however, take up more time about the mere manufacture, but go a little farther into the matter. I have not yet referred you to luxuries in candles (for there is such a thing as luxury in candles). See how beautifully these are coloured; you see here mauve, magenta, and all the chemical colours recently introduced, applied to candles. You observe, also, different forms employed. Here is a fluted pillar most beautifully shaped; and I have also here some candles sent me by Mr. Pearsall, which are ornamented with designs upon them, so that, as they burn, you have, as it were, a glowing sun above, and bouquet of flowers beneath. All, however, that is fine and beautiful is not useful. These fluted candles, pretty as they are, are bad candles; they are bad because of their external shape. Nevertheless, I show you these specimens, sent to me from kind friends on all sides, that you may see what is done and what may be done in this or that direction; although, as I have said, when we come to these refinements, we are obliged to sacrifice a little in utility.

Now as to the light of the candle. We will light one or two, and set them at work in the performance of their proper functions. You observe a candle is a very different thing from a lamp. With a lamp you take a little oil, fill your vessel, put in a little moss or some cotton prepared by artificial means, and then light the top of the wick. When the flame runs down the cotton to the oil, it gets extinguished, but it goes on burning in the part above. Now I have no doubt you will ask how it is that the oil which will not burn of itself gets up to the top of the cotton, where it will burn. We shall presently examine that; but there is a much more wonderful thing about the burning of a candle than this. You have here a solid substance with no vessel to contain it; and how is it that this solid substance can get up to the place where the flame is? How is it that this solid gets there, it not being a fluid? or, when it is made a fluid, then how is it that it keeps together? This is a wonderful thing about a candle.

We have here a good deal of wind, which will help us in some of our illustrations, but tease us in others; for the sake, therefore, of a little regularity, and to simplify the matter, I shall make a quiet flame, for who can study a subject when there are difficulties in the way not belonging to it? Here is a clever invention of some costermonger or street-stander in the market-place for the shading of their candles on Saturday nights, when they are selling their greens, or potatoes, or fish. I have very often admired it. They put a lamp-glass round the candle, supported on a kind of gallery, which clasps it, and it can be slipped up and down as required. By the use of this lamp-glass, employed in the same way, you have a steady flame, which you can look at, and carefully examine, as I hope you will do, at home.

You see, then, in the first instance, that a beautiful cup is formed. As the air comes to the candle, it moves upward by the force of the current which the heat of the candle produces, and it so cools all the sides of the wax, tallow, or fuel as to keep the edge much cooler than the part within; the part within melts by the flame that runs down the wick as far as it can go before it is extinguished, but the part on the outside does not melt. If I made a current in one direction, my cup would be lop-sided, and the fluid would consequently run over; for the same force of gravity which holds worlds together holds this fluid in a horizontal position, and if the cup be not horizontal, of course the fluid will run away in guttering. You see, therefore, that the cup is formed by this beautifully regular ascending current of air playing upon all sides, which keeps the exterior of the candle cool. No fuel would serve for a candle which has not the property of giving this cup, except such fuel as the Irish bogwood, where the material itself is like a sponge and holds its own fuel. You see now why you would have had such a bad result if you were to burn these beautiful candles that I have shown you, which are irregular, intermittent in their shape, and can not, therefore, have that nicely-formed edge to the cup which is the great beauty in a candle. I hope you will now see that the perfection of a process - that is, its utility - is the better point of beauty about it. It is not the best looking thing, but the best acting thing, which is the most advantageous to us. This good-looking candle is a bad-burning one. There will be a guttering round about it because of the irregularity of the stream of air and the badness of the cup which is formed thereby. You may see some pretty examples (and I trust you will notice these instances) of the action of the ascending current when you have a little gutter run down the side of a candle, making it thicker there than it is elsewhere. As the candle goes on burning, that keeps its place and forms a little pillar sticking up by the side, because, as it rises higher above the rest of the wax or fuel, the air gets better round it, and it is more cooled and better able to resist the action of the heat at a little distance. Now the greatest mistakes and faults with regard to candles, as in many other things, often bring with them instruction which we should not receive if they had not occurred. We come here to be philosophers, and I hope you will always remember that whenever a result happens, especially if it be new, you should say, "What is the cause? Why does it occur?" and you will, in the course of time, find out the reason.

Then there is another point about these candles which will answer a question - that is, as to the way in which this fluid gets out of the cup, up the wick, and into the place of combustion. You know that the flames on these burning wicks in candles made of

beeswax, stearin, or spermaceti, do not run down to the wax or other matter, and melt it all away, but keep to their own right place. They are fenced off from the fluid below, and do not encroach on the cup at the sides. I can not imagine a more beautiful example than the condition of adjustment under which a candle makes one part subserve to the other to the very end of its action. A combustible thing like that, burning away gradually, never being intruded upon by the flame, is a very beautiful sight, especially when you come to learn what a vigorous thing flame is - what power it has of destroying the wax itself when it gets hold of it, and of disturbing its proper form if it come only too near.

But how does the flame get hold of the fuel? There is a beautiful point about that - capillary attraction.⁵ "Capillary attraction!" you say - "the attraction of hairs." Well, never mind the name; it was given in old times, before we had a good understanding of what the real power was. It is by what is called capillary attraction that the fuel is conveyed to the part where combustion goes on, and is deposited there, not in a careless way, but very beautifully in the very midst of the centre of action, which takes place around it. Now I am going to give you one or two instances of capillary attraction. It is that kind of action or attraction which makes two things that do not dissolve in each other still hold together. When you wash your hands, you wet them thoroughly; you take a little soap to make the adhesion better, and you find your hands remain wet. This is by that kind of attraction of which I am about to speak. And, what is more, if your hands are not soiled (as they almost always are by the usages of life), if you put your finger into a little warm water, the water will creep a little way up the finger, though you may not stop to examine it. I have here a substance which is rather porous - a column of salt - and I will pour into the plate at the bottom, not water, as it appears, but a saturated solution of salt which can not absorb more, so that the action which you see will not be due to its dissolving any thing. We may consider the plate to be the candle, and the salt the wick, and this solution the melted tallow. (I have coloured the fluid, that you may see the action better.) You observe that, now I pour in the fluid, it rises and gradually creeps up the salt higher and higher; and provided the column does not tumble over, it will go to the top. If this blue solution were combustible, and we were to place a wick at the top of the salt, it would burn as it entered into the wick. It is a most curious thing to see this kind of action taking place, and to observe how singular some of the circumstances are about it. When you wash your hands, you take a towel to wipe off the water; and it is by that kind of wetting, or that kind of attraction which makes the towel become wet with water, that the wick is made wet with the tallow. I have known some careless boys and girls (indeed, I have known it happen to careful people as well) who, having washed their hands and wiped them with a towel, have thrown the towel over the side of the basin, and before long it has drawn all the water out of the basin and conveyed it to the floor, because it happened to be thrown over the side in such a way as to serve the purpose of a siphon. That you may the better see the way in which the substances act one upon another, I have here a vessel made of wire gauze filled with water, and you may compare it in its action to the cotton in one respect, or to a piece of calico in the other. In fact, wicks are sometimes made of a kind of wire gauze. You will observe that this vessel is a porous thing; for if I pour a little water on to the top, it will run out at the bottom. You would be puzzled for a good while if I asked you what the state of this vessel is, what is inside it, and why it is there? The vessel is full of water, and yet you see the water goes in and

runs out as if it were empty. In order to prove this to you, I have only to empty it. The reason is this: the wire, being once wetted, remains wet; the meshes are so small that the fluid is attracted so strongly from the one side to the other, as to remain in the vessel, although it is porous. In like manner, the particles of melted tallow ascend the cotton and get to the top: other particles then follow by their mutual attraction for each other, and as they reach the flame they are gradually burned.

Here is another application of the same principle. You see this bit of cane. I have seen boys about the streets, who are very anxious to appear like men, take a piece of cane, and light it, and smoke it, as an imitation of a cigar. They are enabled to do so by the permeability of the cane in one direction, and by its capillarity. If I place this piece of cane on a plate containing some camphene (which is very much like paraffine in its general character), exactly in the same manner as the blue fluid rose through the salt will this fluid rise through the piece of cane. There being no pores at the side, the fluid can not go in that direction, but must pass through its length. Already the fluid is at the top of the cane; now I can light it and make it serve as a candle. The fluid has risen by the capillary attraction of the piece of cane, just as it does through the cotton in the candle.

Now the only reason why the candle does not burn all down the side of the wick is that the melted tallow extinguishes the flame. You know that a candle, if turned upside down, so as to allow the fuel to run upon the wick, will be put out. The reason is, that the flame has not had time to make the fuel hot enough to burn, as it does above, where it is carried in small quantities into the wick, and has all the effect of the heat exercised upon it.

There is another condition which you must learn as regards the candle, without which you would not be able fully to understand the philosophy of it, and that is the vaporous condition of the fuel. In order that you may understand that, let me show you a very pretty but very commonplace experiment. If you blow a candle out cleverly, you will see the vapour rise from it. You have, I know, often smelt the vapour of a blown-out candle, and a very bad smell it is; but if you blow it out cleverly you will be able to see pretty well the vapour into which this solid matter is transformed. I will blow out one of these candles in such a way as not to disturb the air around it by the continuing action of my breath; and now, if I hold a lighted taper two or three inches from the wick, you will observe a train of fire going through the air till it reaches the candle. I am obliged to be quick and ready, because if I allow the vapour time to cool, it becomes condensed into a liquid or solid, or the stream of combustible matter gets disturbed.

Now as to the shape or form of the flame. It concerns us much to know about the condition which the matter of the candle finally assumes at the top of the wick, where you have such beauty and brightness as nothing but combustion or flame can produce. You have the glittering beauty of gold and silver, and the still higher lustre of jewels like the ruby and diamond; but none of these rival the brilliancy and beauty of flame. What diamond can shine like flame? It owes its lustre at night-time to the very flame shining upon it. The flame shines in darkness, but the light which the diamond has is as nothing until the flame shines upon it, when it is brilliant again. The candle alone shines by itself and for itself, or for those who have arranged the materials. Now let us look a little at the

form of the flame as you see it under the glass shade. It is steady and equal, and its general form is that which is represented in the diagram, varying with atmospheric disturbances, and also varying according to the size of the candle. It is a bright oblong, brighter at the top than toward the bottom, with the wick in the middle, and, besides the wick in the middle, certain darker parts towards the bottom, where the ignition is not so perfect as in the part above. I have a drawing here, sketched many years ago by Hooker, when he made his investigations. It is the drawing of the flame of a lamp, but it will apply to the flame of a candle. The cup of the candle is the vessel or lamp; the melted spermaceti is the oil; and the wick is common to both. Upon that he sets this little flame, and then he represents what is true, a certain quantity of matter rising about it which you do not see, and which, if you have not been here before, or are not familiar with the subject, you will not know of. He has here represented the parts of the surrounding atmosphere that are very essential to the flame, and that are always present with it. There is a current formed, which draws the flame out; for the flame which you see is really drawn out by the current, and drawn upward to a great height, just as Hooker has here shown you by that prolongation of the current in the diagram. You may see this by taking a lighted candle, and putting it in the sun so as to get its shadow thrown on a piece of paper. How remarkable it is that that thing which is light enough to produce shadows of other objects can be made to throw its own shadow on a piece of white paper or card, so that you can actually see streaming round the flame something which is not part of the flame, but is ascending and drawing the flame upward. Now I am going to imitate the sunlight by applying the voltaic battery to the electric lamp. You now see our sun and its great luminosity; and by placing a candle between it and the screen, we get the shadow of the flame. You observe the shadow of the candle and of the wick; then there is a darkish part, as represented in the diagram, and then a part which is more distinct. Curiously enough, however, what we see in the shadow as the darkest part of the flame is, in reality, the brightest part; and here you see streaming upward the ascending current of hot air, as shown by Hooker, which draws out the flame, supplies it with air, and cools the sides of the cup of melted fuel.

I can give you here a little farther illustration, for the purpose of showing you how flame goes up or down according to the current. I have here a flame - it is not a candle flame - but you can, no doubt, by this time generalize enough to be able to compare one thing with another. What I am about to do is to change the ascending current that takes the flame upward into a descending current. This I can easily do by the little apparatus you see before me. The flame, as I have said, is not a candle flame, but it is produced by alcohol, so that it shall not smoke too much. I will also colour the flame with another substance⁶, so that you may trace its course; for, with the spirit alone, you could hardly see well enough to have the opportunity of tracing its direction. By lighting this spirit of wine we have then a flame produced, and you observe that when held in the air it naturally goes upward. You understand now, easily enough, why flames go up under ordinary circumstances: it is because of the draught of air by which the combustion is formed. But now, by blowing the flame down, you see I am enabled to make it go downward into this little chimney, the direction of the current being changed. Before we have concluded this course of lectures we shall show you a lamp in which the flame goes up and the smoke goes down, or the flame goes down and the smoke goes up. You see, then, that we have the power in this way of varying the flame in different directions.

There are now some other points that I must bring before you. Many of the flames you see here vary very much in their shape by the currents of air blowing around them in different directions; but we can, if we like, make flames so that they will look like fixtures, and we can photograph them indeed, we have to photograph them - so that they become fixed to us, if we wish to find out every thing concerning them. That, however, is not the only thing I wish to mention. If I take a flame sufficiently large, it does not keep that homogeneous, that uniform condition of shape, but it breaks out with a power of life which is quite wonderful. I am about to use another kind of fuel, but one which is truly and fairly a representative of the wax or tallow of a candle. I have here a large ball of cotton, which will serve as a wick. And, now that I have immersed it in spirit and applied a light to it, in what way does it differ from an ordinary candle? Why, it differs very much in one respect, that we have a vivacity and power about it, a beauty and a life entirely different from the light presented by a candle. You see those fine tongues of flame rising up. You have the same general disposition of the mass of the flame from below upward; but, in addition to that, you have this remarkable breaking out into tongues which you do not perceive in the case of a candle. Now, why is this? I must explain it to you, because, when you understand that perfectly, you will be able to follow me better in what I have to say hereafter. I suppose some here will have made for themselves the experiment I am going to show you. Am I right in supposing that any body here has played at snapdragon? ⁷ I do not know a more beautiful illustration of the philosophy of flame, as to a certain part of its history, than the game of snapdragon. First, here is the dish; and let me say, that when you play snapdragon properly you ought to have the dish well warmed; you ought also to have warm plums, and warm brandy, which, however, I have not got. When you have put the spirit into the dish, you have the cup and the fuel; and are not the raisins acting like the wicks? I now throw the plums into the dish, and light the spirit, and you see those beautiful tongues of flame that I refer to. You have the air creeping in over the edge of the dish forming these tongues. Why? Because, through the force of the current and the irregularity of the action of the flame, it can not flow in one uniform stream. The air flows in so irregularly that you have what would otherwise be a single image broken up into a variety of forms, and each of these little tongues has an independent existence of its own. Indeed, I might say, you have here a multitude of independent candles. You must not imagine, because you see these tongues all at once, that the flame is of this particular shape. A flame of that shape is never so at any one time. Never is a body of flame, like that which you just saw rising from the ball, of the shape it appears to you. It consists of a multitude of different shapes, succeeding each other so fast that the eye is only able to take cognisance of them all at once. In former times I purposely analysed a flame of that general character, and the diagram shows you the different parts of which it is composed. They do not occur all at once; it is only because we see these shapes in such rapid succession that they seem to us to exist all at one time.

It is too bad that we have not got farther than my game of snapdragon; but we must not, under any circumstances, keep you beyond your time. It will be a lesson to me in future to hold you more strictly to the philosophy of the thing than to take up your time so much with these illustrations.

1 Fire-damp is methane, CH_4 , explosive with air. The Davy lamp enabled its safe detection, and Davy it was who employed Faraday at the RI.

2 The Royal George sank at Spithead on the 29th of August, 1782. Colonel Pasley commenced removal of the wreck in August 1839.

3 The fat (tallow) undergoes alkaline hydrolysis to calcium palmitate, oleate and stearate, and glycerol (glycerine). The free acids are liberated with hot dilute sulphuric acid. The melted fatty acids rise as an oil to the surface and are skimmed off. They are washed and cast into thin plates, which, when cold, are placed between layers of coconut matting and submitted to high pressure. The soft oleic acid is squeezed out, while the hard palmitic and stearic acids remain. These are further purified by compressing at a higher temperature and washing in warm dilute sulphuric acid, when they are ready to be made into candles. These acids are harder and whiter than the fats from which they were obtained, and burn more easily and cleanly.

4 Glycerol gets its name from its sweet taste. It is propan-1,2,3-triol, $\text{HOCH}_2\text{CH}(\text{OH})\text{CH}_2\text{OH}$. It is essentially a three-carbon sugar.

5 Capillary attraction or repulsion arises from the surface tension of a liquid. If a capillary tube is placed in a liquid which will wet the tube, liquid rises up it until the upwards force from the surface tension is balanced by the weight of the liquid column. Candle wax is drawn up the wick for this reason - it wets it.

6 Faraday added copper(II) chloride to colour the flame green.

APPENDIX B

Properties of Solid Fuels

Density (ρ)	Substance's mass divided by its volume	Kg/m³
Thermal Conductivity (k)	Ability to absorb and transmit heat energy	W/m-K
Specific Heat: (c)	Substance's ability to store heat energy	J/kg-K (J/mol-K)
Thermal diffusivity: (α)	Property of (ρ) and (k) divided by specific heat (c)	Kp/c

Properties of Solid Fuels

Thermal Resistance: (R - value)	Measure of ability to resist heat flow	kA/l
Thermal Inertia: (kpc)	Solids with higher values req. higher quantities of energy in order to ignite.	
Heat of (L) Gasification:	Energy needed to convert solid (liquid) to gaseous state	kJ/kg
Heat of Fusion:	Energy req. to convert 1 g of material from solid to liquid	calories

Thermal Properties-Common Fuels

Substance	(k) W/m-K	(c) kJ/kg-K	(ρ) kg/m ³	(α) m ² /s	(kρc) kW ² - s/m ⁴ - K ²
Copper	387	.380	8940	1.14x10 ⁻⁴	1300
Steel	45.8	.460	7850	1.126x10 ⁻⁵	160
Concrete	0.8-1.4	.880	2100±	5.7x10 ⁻⁷	2.0
Oak	0.17	2.380	800	8.9x10 ⁻⁸	0.32
Poly-urethane	0.034	1.40	20	1.2x10 ⁻⁶	9.5x10 ⁻⁴
Air	0.026	1.040	1.1	2.2x10 ⁻⁵	3.0x10 ⁻⁵

D. Drysdale. *An Introduction to Fire Dynamics*, 1985.

Properties of Liquid Fuels

Boiling Point	Temperature at which a liquid changes to a gas phase. Temp. varies with pressure.
Flashpoint	Temp. of liquid at evaporated state, where ignition will occur with an open flame (piloted ignition)
Specific Gravity	Comparison of the density of equal volumes of a liquid to water. Water has a value of 1 . Liquids with a value < 1 will float on water, & liquids with value > 1 will sink in water

Properties of Liquid Fuels

Evaporation	The rate of evaporation is dependent upon the temperature of the liquid.	
Heat of vaporization: (<i>L</i>)	Amount of energy required to convert a liquid to a gaseous state (also heat of gasification)	kJ/kg

Thermal Properties- Common Liquids

	Flashpoint °C	Boiling point °C	Auto- Ignition °C	(L) kJ/g
Gasoline	-43	32-190	280	0.33
Kerosene	38	175-300	210	0.67
Peanut Oil	445		282	
Paraffin Wax	204-271		245	

Properties of Gaseous Fuels

Vapor Pressure	Assuming a liquid is in a closed system. Liquid will evaporate and form vapors until equilibrium is attained. A saturated evaporation state is reached when the liquid no longer permits evaporation.	mmHg
Vapor Density	Value describing the average molecular weight of a gas or vapor compared to atmospheric oxygen (which is assigned a value of 1. If vapor density <1, gas will rise ; and if >1, the gas will sink .	

Properties of Gaseous Fuels

Fuel/Air Ratio: (%)	Potential to ignite concentrations of flammable gases w/atmospheric oxygen
Lower Flammable Limit: (LFL)	Lower limits of fuel/air mixture where combustion will not occur due to fuel being too lean . Also known as Lower Explosive Limit (LEL)
Upper Flammable Limit: (UFL)	Upper limits of fuel/air mixture where combustion will not occur due to fuel being too rich . Also known as Upper Explosive Limit (UEL)

Thermal Properties-Gaseous Fuels

	Auto-Ign.-C	Vapor Density	Δh_c (MJ/K/m³)	LEL-UEL	Fuel/Air
Butane	405	1.93	1112.4	1.8-8/4	15.7
CO	609	0.97	11.7	12.5-74	
H	400	.07	21.1	4-75	34.7
Methane	540	.55	34	5-15	17.2
Propane	450	1.51	86.4	2.1-9.5	15.7

(Harris, R.J. "The Investigation and Control of Gas Explosions." Ch. In *SFPE Handbook*, 1995 ed. New York: E & FN Spon, 1983.)

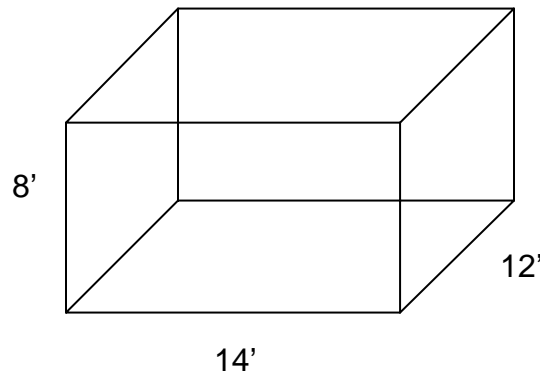
Mathematical Precourse Preparation Review

Solve the following algebraic and geometry problems using methods discussed and referenced in this unit. Show all of your work and use additional paper if necessary. All questions are worth a two points, unless noted otherwise.

- Utilizing the principles of Dimensional Analysis, convert $20\text{kw}/\text{m}^2$ to an equivalent value expressed as w/cm^2 . Show all of your work, including cancellation units.

$$\frac{20\text{kW}}{1\text{m}^2} =$$

- In English units, determine the volume, surface area, and perimeter of the walls for a room with dimensions displayed below. Exclude the floor area of the room.



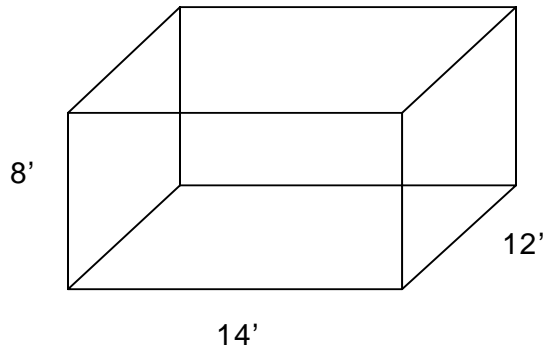
Volume:

Surface area:

Perimeter of room:

3. Convert the above room dimensions into meters and re-calculate the room volume, surface area, and perimeter of the walls. Again, excluding the floor area of the room. Metric equivalents should be carried-out to the 100th place.

Example: 3.7653 meters would be rounded upwards to 3.77 meters.
3.7648 meters would be rounded-downward to 3.76 meters.



Volume:

Surface area:

Perimeter of room:

4. Develop a linear equation which defines the total distance of fire spread, when the fire is first observed to be 3' wide, and progresses at a rate of 1" per second. Convert the listed dimensions to metric, prior to creating the equation.

5. Following the order of operations, solve the below expressions:

- a. (1 point)

$$[8 \times 7 \div 4 + 3(6 - 2)] \times 2$$

- b. (2 points)

$$\frac{36 + 3^2}{5} \div 18 + [(\sqrt{9} - 1 + 6) \times 5(6 + 1)] + 16/32$$

6. The metric surface area of a sphere in meters, with a radius of 32" is:

7. Express the number 598,432,000 in scientific notation: (1 point)

8. Convert the below exponential expression into a fraction:

$$5^{-2} =$$

9. Convert the below exponential variable expression into a radical expression:

$$a^{\frac{5}{2}} =$$

10. Re-write the below expression in the form of a radical.

$$x^{\frac{4}{5}} =$$

11. Convert the below exponential expression into a radical, and then solve:

$$2^{\frac{5}{2}} =$$

12. Convert the below exponential expression into a fraction containing a radical, and then solve (result is an irrational number): (3 points)

$$2^{-\frac{4}{3}} =$$

13. Re-write the below radical expression as a variable with an exponential expression:

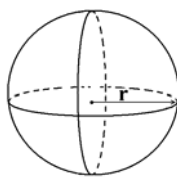
$$\frac{4}{\sqrt{x}} =$$

14. True or false, does $\sqrt{x^7} = (\sqrt{x})^7$ (circle correct answer – 1 point).

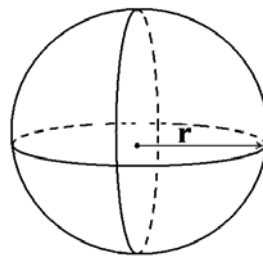
15. Determine the surface area of a sphere having a diameter of 2.4 meters:
16. (Bonus Problem--4 points) Applying the rules of simplification, form an equation which solves for the flame height (H_f).

$$\dot{Q} = \frac{79.18 H_f^{5/2}}{k}$$

17. Describe the principle of radiative energy decreasing over distance by comparing the two spheres below. Your answer should be expressed as a percentage of reduction in radiative energy. Area of sphere (Unit 2) = $A = 4\pi r^2$



$r = 1.2$ meters



$r = 2.4$ meters

18. The measure of the rate of heat transfer to a surface is called?
- a. Energy rate
 - b. Heat flux
 - c. Heat of gasification
 - d. Dynes
19. List three principle means of heat transfer:
- _____
- _____
- _____
20. Heat transfer is a major factor in which of the following phases of a fire?
- a. Ignition.
 - b. Growth.
 - c. Decay.
 - d. All of the above.
-

21. Most fuels must be vaporized or pyrolyzed in order to sustain the generation of flammable gases needed for combustion.
- a. True
 - b. False
22. A fire which produces a fuel rich environment within a sealed-off compartment is
- a. Fuel limited.
 - b. Confined.
 - c. Ventilation limited.
 - d. Lack of latent heat.
23. The above fire would be characterized as being part what system?
- a. Open system.
 - b. Closed system.
 - c. Mechanical deficient system.
 - d. All of the above.
24. The transition phase in a contained fire in which surfaces exposed to thermal radiation reach ignition temperature more or less simultaneously and fire spreads rapidly throughout the space is called
- a. Flame over.
 - b. Backdraft.
 - c. Deflagration.
 - d. Flashover.
 - e. Heat Flux.
25. Initiation of combustion by heat without a spark or flame is called
- a. Radiation.
 - b. Thermal Ignition.
 - c. Autoignition.
 - d. Piloted ignition.
26. As an unconfined fire plume rises, it becomes
- a. Cooler and faster.
 - b. Cooler and wider.
 - c. Wider and faster.
 - d. Wider and temperature remains constant.
-

27. The presence of thick oily smoke and soot on glass of a fire compartment can be the result of incomplete combustion of what type of fuel?
-
28. As fire gases vent out of a window of a structure, the elongated flames can be related to what phenomenon:
- a. Fick's Law.
 - b. Charles Law.
 - c. Bernoulli Principle.
 - d. Boyles Law.
29. Balance the below chemical equation, assuming conservation of matter:
- $$2 \text{C}_4\text{H}_{10} + 13 \text{O}_2 \rightarrow \text{---} \text{CO}_2 + \text{---} \text{H}_2\text{O}$$
30. The amount of energy required to convert a solid (or liquid) material to a gaseous combustible state is:
- a. Heat of fusion.
 - b. Thermal inertia.
 - c. Specific Heat.
 - d. Heat of gasification.
31. The temperature at which a liquid changes to a gas phase is referred to as it's:
- a. Flashpoint.
 - b. Evaporation state.
 - c. Boiling point.
 - d. Heat of vaporization.
32. Heat Release Rate is controlled by
- a. The phase of a given material.
 - b. Chemical and physical properties of fuel.
 - c. British Thermal Units.
 - d. The ignition source.
33. Ignition Energy is
- a. Thermal inertia.
 - b. Flammability range.
 - c. Minimum amount of energy transferred to the fuel to trigger the first oxidation.
 - d. Decomposition of a material into simpler compounds brought about by heat.
-

34. The severity and duration of the fire will be dependant upon
- a. Geometry of fuel.
 - b. Configuration of fuel.
 - c. Condition of fuel.
 - d. All of the above.
35. Thermal conductivity represents
- a. The ability to transfer heat by conduction.
 - b. An example of air entrainment
 - c. An indication of whether prolonged heating occurred prior to ignition.
 - d. Fire that is fuel controlled.
36. This graphic illustrates:



- a. Confined by ceiling.
 - b. Confined by wall.
 - c. Confined by corner.
 - d. None of the above.
37. In a fuel controlled fire:
- a. The combustion inside the compartment will be incomplete.
 - b. Products of incomplete combustion will leave the compartment.
 - c. The combustion will be limited by the amount of air entering the compartment.
 - d. Fire usually has an excess of ventilation.
38. Ventilation generated patterns
- a. May be mistaken for patterns originating from ignitable liquids.
 - b. Are affected by general conditions such as open/closed doors.
 - c. Are affected by turbulence in the combustion process.
 - d. All of the above.
-

39. Flashover is
- a. A specific moment or event.
 - b. A transition phase when surfaces exposed to thermal radiation reach ignition temperature.
 - c. The target fuel.
 - d. Always ventilation controlled.
40. Controlling factors of backdraft include:
- a. Fuel properties, compartment size, ventilation.
 - b. Building construction, structural damage, ceiling composition.
 - c. Pyrolyzed target fuel, flux level.
 - d. Smoke, ignition vapor cloud, HVAC.
41. Heat of combustion is:
- a. Energy needed to increase temperature of fuel.
 - b. Energy needed to cause ignition.
 - c. Amount of heat any fuel can produce when burned.
 - d. Phase of a given material dependant on the temperature and pressure.
-

NFA WELCOME PACKAGE

Below is information to help you plan your travel to the National Emergency Training Center (NETC). Even if you've taken classes at NETC previously, please read it carefully. ***The procedures may have changed since you were here last, and you will be responsible for complying with the current procedures.*** The last page of this package is entitled "CONTACT INFORMATION." We suggest you print it and provide a copy to your family and office staff in case they need to contact you **while you are here**. Although *friends or family may not stay in Housing*, they are welcome to attend graduation. Please contact Security before their arrival for current security protocol required for their entry to NETC campus.

If you have any questions, you may call us at either (800) 238-3358 or (301) 447-1000. When you reach the operator, ask for the appropriate extension:

- **Housing/Transportation---1048/1113**
- **Admissions---1035**
- **Food Service (Guest Services)---1551**
- **Security---1111**

You may send an email to:

- **Housing/Transportation:** NETC-Housing@dhs.gov
- **Admissions:** NETC-admissions@dhs.gov
- **Food Service:** NETC-cafeteria@dhs.gov

If you need to fax information to any of the following offices, please note the following fax numbers:

- **Housing/Transportation:** (301) 447-1324
- **Admissions:** (301) 447-1441
- **Food Service:** (301) 447-6944



SECURITY



Due to increased security precautions, students should bring two photo ID's to campus. PLEASE HAVE THEM WITH YOU, NOT IN YOUR BAGGAGE! If you do not have the photo ID's, you will not be permitted on campus. Security checks will delay your registration at the NETC.

If you are a student from a foreign country, please be prepared to show your passport or visa at registration.

Firearms: Prohibited on campus!

Due to heightened security requirements, please understand that security and law enforcement personnel may search you, your vehicle or your luggage. Maryland law is very narrow in its definition of law enforcement officers who may carry firearms. For your own protection, and to expedite your processing into the NETC, **do not bring weapons of any kind to campus**. Weapons include knives with blades longer than 3 inches, machete, bow & arrows, ammunition, rifles, shotguns, pistols, etc. Sworn/commissioned, and state POST certified officers and federal officers, or local officers with concurrent jurisdiction who require a firearm for the performance of required official duties must obtain an exception from the Director of Support Services prior to arrival on campus. If you arrive at NETC with weapons of any kind without prior approval, your entry to campus will be significantly delayed.

Alcoholic Beverages: Consumption of alcoholic beverages is limited to the Pub & Log Cabin. Alcohol is not allowed in lodging rooms or vehicles, and will be confiscated. If you arrive at NETC with, or are attempting to bring alcohol on campus, your entry to campus could be significantly delayed.



TRAVEL



TRAVEL BY AIR:

- You **must** make your own travel arrangements.
- You **must** be sure your flights meet the shuttle pickup/departure times, and the ticket purchase follows the parameters of travel as defined under “**REIMBURSEMENT**” in this package.

NETC SHUTTLE SERVICE:

- Shuttle service is available between NETC and the airport(s) listed on the “COURSE SPECIFIC INFORMATION” sheet – a pink page enclosed with the acceptance letter you received for this class. **Read it carefully before making flight arrangements!**
- If you need bus transportation to NETC from the airport, you should plan to arrive at least 1 hour before bus departure time. **You must notify (email, phone or fax) the NETC Transportation Office at least 1 week prior to the course start-date to reserve a seat. IF YOU DO NOT CALL, SEATING MAY NOT BE AVAILABLE AND TRANSPORTATION TO EMMITSBURG WILL BE AT YOUR OWN EXPENSE.**
- **Our transportation will be either a motor coach/charter bus identified with NETC signage in the front window/door, or a maroon passenger van with the NETC signage in the front window.** You may contact the NETC Transportation Office a day before your arrival to inquire as to which vehicle will be used. For airport security reasons, **our drivers cannot leave their vehicles** and must circle the airport pickup area, **SO YOU WILL NEED TO LOOK FOR THE BUS OR VAN. If you do not see the vehicle 5 minutes prior to the pickup time, please call the NETC Transportation Office for guidance.**

SHUTTLE PICKUP POINTS AT EACH AIRPORT: (check your pink “Course Specific Information” sheet as to which airport you may use. **You can ONLY use an airport listed on that sheet!** Ground transportation from other airports may be at your own expense. If your **scheduled arrival time** does not coincide with the shuttle schedule, ground transportation will be at your own expense as well.)

- **Ronald Reagan National Airport (DCA):** Pickup is near the Travelers’ Aid Desk in Terminal ‘B’ (Lower Level, between gates 5 & 6). **Buses and vans** depart from the outside lane. If you arrive in Terminal ‘A’ please take the Economy/Rental Car airport bus shuttle to Terminal ‘B’, lower level, or walk across the terminal connector and go downstairs to exit door number 5, on your left.
- **Baltimore/Washington International Airport (BWI):** Pickup is near the Lower Level Baggage Areas 13 & 14. There is not a Travelers’ Aid Desk in this location. Buses and vans depart from the outside lane. BWI Airport is currently undergoing construction. If you have any questions or concerns, please contact the NETC Transportation Office or visit the BWI website at:
http://www.bwiairport.com/customer_assistance/lower_level_terminal-map
- **Dulles International Airport (IAD):** There is a Traveler’s Aid Desk between Baggage Claim Areas 4 & 5 on the baggage level, located at the east end of the terminal. Go up the ramp and out exit-door number 6.

DELAYED FLIGHTS: If you are scheduled to use NETC transportation, but your flight is delayed for other than weather-related reasons, the airline is responsible for your transportation. If they will not transport you, please call the NETC Transportation Office when you arrive at the airport (it will be approximately 2 hours before we can pick you up). **If you choose not to use NETC transportation and arrange for other transportation, it will be at your own expense.**

IF DRIVING:

- You may arrive on campus any time after 12:30 p.m. the day before your course begins.
- You must depart campus after the end of your course, except for courses with a next-day departure date.

- Your vehicle must be registered at Housing/Security for stipend/security reasons, even if you do not stay on campus.
- **There are no connections for mobile homes or recreational vehicles available at NETC.**

DIRECTIONS TO NETC:

- **From Baltimore:** I-695 (Baltimore Beltway) to I-70 West (towards Frederick) to Route 15 North to Emmitsburg. Left turn off Route 15 to South Seton Avenue. 2nd Right onto campus (tree-lined drive).
- **From Washington:** I-495 (Washington Beltway) to I-270 North (towards Frederick) to Route 15 North to Emmitsburg. Left turn off Route 15 to South Seton Avenue. 2nd Right onto campus (tree-lined drive).
- **From Philadelphia and East:** Pennsylvania Turnpike West to Harrisburg, Exit 236 (Route 15). Go South on Route 15 to Emmitsburg. Right turn off Route 15 to South Seton Avenue. 2nd Right onto campus (tree-lined drive).
- **From Pittsburgh and West:** Pennsylvania Turnpike East to Harrisburg, Exit 236 (Route 15). Go South on Route 15 to Emmitsburg. Right turn off Route 15 to South Seton Avenue. 2nd Right onto campus (tree-lined drive).



REGISTRATION



Where do I register?

- Class, dormitory, and vehicle registration will take place in Building C Lobby.
- Since you may have to walk some distance to your room, we recommend you bring luggage with wheels.

If I am claiming stipend reimbursement, what do I need to provide at registration?

- **A copy of a check for an account that bears your name.** Deposit slips or accounts for an organization or another individual are not acceptable; a copy of a check is the best source for the correct financial information.
- We've found it speeds up registration if you fax the information to the Admissions Office (301) 447-1441 **prior** to your course start date. Please include your name, Social Security Number, and course code/title/date on the fax along with your vehicle or flight information. Please be sure that the copy is legible.
- If your account is with a credit union, or if the account is payable through another bank, please have the bank provide you with the routing and account numbers for ACH deposit.
- If you incurred additional expenses for transportation/lodging/meal costs, **you must receive prior written approval** to be eligible for reimbursement of these expenses. If approved, **original receipts must** be presented at the time of your arrival.
- **If traveling by air or train you will need:**
 - **A copy of your ticket** that shows an itinerary of your trip indicates proof that the ticket was purchased at least 21-days in advance of the course travel date, and is non-refundable.
 - If you have an electronic ticket, you must submit the itinerary/receipt (with ticket number and actual ticket amount shown as having been paid).
- **If driving, you will also need to provide:**
 - **Automobile registration**
 - **Odometer readings**
 - **License tag number**
 - **A signed statement from the owning agency on letterhead stationery acknowledging your eligibility for reimbursement, if you are driving a state, county or municipal vehicle**
 - If you drove to NETC, but you will not be keeping your car on campus, it **must be registered on campus or you will not** receive reimbursement.

What if I am here for back-to-back courses?

- You will be housed in the same room for the entire length of the stay. If you stay off-campus and do not purchase a meal ticket for the time between the courses, you must check out of housing after the first course ends (turn in the keycard and remove your belongings), and be assigned a new room upon your return.
- **If you choose to leave campus between courses**, any additional expenses that you may incur shall remain your responsibility.



LODGING

Must I call to make a lodging reservation?

- No, rooms are assigned once you are accepted into a course. Because of the random assignment, you may or may not be lodged in the same building as your classmates.
- We make every effort to ensure you have a single room. However, if the student count is high, you may be doubled with another student. **PLEASE DO NOT CALL TO REQUEST A SINGLE ROOM.**
- **IF YOU HAVE A DISABILITY AND NEED SPECIAL ACCOMMODATIONS**, please contact the Admissions office at least 2 weeks prior to your arrival on campus.
- **Some buildings do not have elevators. If that is a problem, please contact Admissions at least 2 weeks prior to your arrival.**

Is there a charge for lodging?

- No, not if you are eligible for stipend reimbursement **or if you are a DHS federal traveler** (see “Reimbursement” section).
- If you **DO** have to pay for lodging, the current charge is \$30/day.
- NETC Housing accepts cash, personal check, travelers check, and credit card (American Express, VISA, MasterCard and Discover).

What if I want to stay off campus? If you choose to stay off campus, it will be at your own expense. You will still need to purchase a break ticket from **the food service contractor** for the length of your class.

What amenities are in each room?

- Private bathroom
- TV and clock radio
- Refrigerator
- Linens and towels, with daily housekeeping service.
- Telephone with voice mail
- A telephone jack is located in each room for dial-up Internet access. Check with your Internet Service Provider (ISP) for local calling area access. Out-of-area ISP accessibility will require credit card, third party or collect billing for access from NETC. You should consider bringing a longer cord (10 ft.) if you are bringing your laptop computer. Some courses require students to bring reports or projects to be shared with the class. It is convenient to bring that information in an electronic format. NETC can support CD-ROM, USB devices and 3-1/2” floppy storage. USB devices will be scanned before being allowed to connect to Government equipment.

Additional costs you could incur during your stay:

- Laundry and vending machines; dry cleaner costs
- Recreation Association pass (\$1) allows use of all recreation facilities and Pub (see section on NETC Recreation Association)
- Class Shirts or Group Donations
- Off campus class dinners

Are there laundry facilities available?

- Yes, there are coin-operated washers and dryers in each lodging building (change available at the convenience store on campus).
- You may purchase laundry supplies at the convenience store on campus.

Are family, friends or pets allowed in the lodging rooms on campus?

- No, **only the assigned NETC student** is allowed in the room. Relatives or friends are not allowed in the rooms, and cannot be lodged on campus. Upon request, the NETC Housing Office will provide information regarding local off campus accommodations; however, you are responsible for arranging and paying for those accommodations.
- Animals are not allowed in campus housing, except for seeing-eye and other service dogs. Please notify the housing office at least 2 weeks in advance if you will be bringing a guide/service dog.

What time must I check out of my room? Check out time is **9:00 a.m.** You may leave your luggage in your room until 9:30 a.m., but it must be packed and by the door. When you return for your luggage, please **do not** use the bathroom facilities if the room has already been cleaned for the next occupant. Please return your key card to the front desk by 9:30 a.m.--you will no longer have access to your room after that time.



DRESS CODE



It is each student's responsibility to use good judgment in selecting attire which projects a professional image, and is appropriate for both climate differences and classroom activities. Generally, the standard is business casual. NFA staff have the authority to make a determination that a student's attire may be inappropriate. Students whose attire is determined to be inappropriate will be required to change into more appropriate clothing before being allowed to continue class.

Acceptable Attire for Classroom Settings:

- **Males:** Shirts with collars; dress jeans. Departmental uniforms; departmental T-Shirts; shoes and socks.
- **Females:** Dresses; blouses; slacks; capris; dress jeans; skirts; skorts; departmental uniforms; departmental T-Shirts, and shoes.

Acceptable Attire for Graduation:

- **Males:** Suits; sports coats; dress shirts with ties or class shirts; dress slacks, or departmental dress uniforms.
- **Females:** Suits or dresses; blouses or class shirts with dress slacks or skirts; or departmental dress uniforms.

Shorts, tank tops, ball caps, etc., are not permitted in the classrooms, auditorium, or dining hall. Bathing suits/trunks are not permitted outside the pool area. No mini skirts. Bare midriffs are not acceptable.

ADMISSIONS POLICIES

Attendance:

- **You are required to attend all sessions of the course.** If you do not, you may not receive a certificate and your stipend may be denied.
- NFA students are limited to one reimbursable trip per fiscal year (Oct 1-Sep 30). If you wish to attend a second NFA class (at your own expense) a letter to that effect must accompany the second application stating that you are waiving your stipend reimbursement.

Substitutions:

- **Substitutions for NFA courses are made from waiting lists;** slots do not belong to the departments.
- All requests to consider an equally qualified person must be in writing and be accompanied by a completed General Admissions Application (FEMA Form 75-5) for the substitute.

Cancellations or No-Shows: NFA's mission for delivery of courses is impaired significantly by cancellations and no-shows. It is very difficult and costly to recruit students at the last minute. Currently there is a 2-year ban on student attendance for students who are no-shows or cancel within 30 days of the course start date without a valid reason. If you receive such a restriction, your **supervisor** needs to send a letter to Admissions explaining the cancellation/no-show.

NETC POLICIES/INFORMATION

Conduct:

- Federal Regulations (available at the LRC).
- FEMA and NETC Instructions (available at C Lobby, dormitory rooms, and on NETC Intranet web site).

Smoking:

- All buildings on campus are **NON-SMOKING**, with the exception of the solarium portion of the Command Post Pub.
- If you smoke in your room, **you will** be asked to leave campus, relinquish your stipend reimbursement, and be charged to clean the room.

Medical services:

- All medical expenses are your responsibility.
- Local hospitals accept medical insurance identification, cash, check, or major credit card.
- If you do not have proof of insurance, expect that payment may be a prerequisite to possible treatment.
- International students should be prepared to pay for medical services in the event the hospital or provider does not accept foreign insurance coverage.

Student Word Processing Center (located in D Basement):

- Provides IBM® compatible Microcomputers with Internet access and printing capabilities.
- Systems utilize Microsoft Windows XP with Microsoft's Office Suite 2003.
- The center is open from 6:00 a.m.-11:00 p.m. every day. There is a technician available Mondays-Fridays from 5:00 p.m.-9:00 p.m., and from 8:00 a.m. till noon on Saturdays.

Learning Resource Center: Located in Building N, the LRC provides current information and resources on fire and emergency management subjects. With its collection of more than 100,000 books, reports, periodicals, and audiovisual materials, the LRC facilitates and supports student and faculty research and supplements classroom lectures and course materials. While classes are in session, the Schedule of Hours for the LRC is as follows:

Monday-Thursday	8:30 a.m. – 9:00 p.m.
Friday	8:30 a.m. – 5:00 p.m.
Saturday	4:00 p.m. – 8:00 p.m.
Sunday	12:00 p.m.- 4:00 p.m.

Telephones:

- Outgoing calls can be placed from your lodging room via calling card, collect, or third-party billing.
- ***You are not allowed to accept collect calls on campus phones. Any and all expenses related to phone use shall remain your responsibility.***

Faxes:

- Fax services are available at the convenience store for a fee.
- You may receive fax messages up to 4 pages in the Housing Office at (301) 447-1324.
- Anything over 4 pages will not be forwarded by Housing. Please use the fax service available at the convenience store, or have it sent by overnight mail.

Automatic Teller Machine: Located in D basement outside of O'Leary's Emporium, and at various locations off campus. Inquire at the registration desk at Building C for additional directions.

Public Transportation: Limited service. Inquire at the registration desk at Building C.

Car Rentals: You may contact the campus convenience store at (301) 447-1493 to arrange car rentals at your expense.

NETC Recreation Association: On the NETC campus, the NETC Recreation Association operates a Pub providing beverage and limited food service each evening. The Pub is a private club under Maryland liquor laws and membership in the Recreation Association is required for service. The cost is \$1.00 per campus stay and membership cards can be obtained from the Pub. Other items provided by the Recreation Association to its members and funded by sale of membership cards and Pub items include:

- Athletic equipment such as softball equipment, volleyballs, basketballs, golf clubs, and fishing equipment
- Keg service for special occasions such as cookouts
- Propane and replacement parts for the gas grills
- Acquisition and maintenance of the Christmas lights at the entrance to the campus
- Karaoke entertainment
- Maintenance of special stage lighting in the Student Center
- Assistance with maintenance of the bicycles
- Bicycle helmets
- Maintenance of the billiard tables and equipment
- Large screen television in the Pub
- Games in the Student Center

NETC recreational activities include:

- Gym with running track
- Exercise room
- Swimming pool
- Tennis/basketball/volleyball (sand and inside) courts
- Bicycles are available in Building H for use by Recreation Association members

Nearby points of interest/recreational facilities (in season):

- National/State parks
- Historic Gettysburg (tours available)
- Golf
- Swimming
- Snow skiing



REIMBURSEMENT



Frequently asked questions/answers about reimbursement procedures are enclosed. Please read them carefully. If you have any questions about your eligibility to receive a stipend please contact Admissions either by email at netc-admissions@dhs.gov or by phone at (301) 447-1035.

Any exceptions to travel must be requested in writing and faxed along with documentation to (301) 447-1441, AND approved in writing prior to making your travel arrangements. Otherwise, your stipend may be denied or limited to the state ceiling amount.

Who is eligible for reimbursement?

- State or local government representatives
- Recognized volunteer organization representatives
- Active emergency management organization representatives
- Representatives from State or local fire organizations
- **If you do not apply for a stipend reimbursement within 60 days following the course start date your stipend reimbursement will be denied.**

Who is NOT eligible for stipend reimbursement?

- Federal government (federal students are subject to federal travel regulations and travel under orders prepared by their office)
- Private Industry employees
- Employees who are contracted to Federal, State or local government entities (such as Rural Metro departments)
- Representatives of a foreign organization

How will I be reimbursed?

- Reimbursement will be electronically deposited into the checking or savings account that you identify.
- **Reimbursement will only be made to an account that bears your name.** You are responsible for reimbursing your department, if applicable. This is a result of increased restrictions by the receiving financial institutions.
- **If you do not have a personal account, please contact the Admissions office prior to your arrival for further instructions.**

If I fail the course, will I be reimbursed?

- If eligible for a stipend, you **will** be reimbursed for the course you failed.
- If you reapply to either EMI or NFA and are accepted, no stipend will be paid for that course, and you will be required to pay for lodging. Once you successfully complete a course, you will once again be eligible to receive a stipend for future courses.

If I fly, what will I be reimbursed? You will be reimbursed the cost of a direct (no side-trips or extended stays), **21-day prior to the course travel date pre-purchase, non-refundable** ticket for round/trip transportation by common carrier (economy coach class or less) for each course or back-to-back courses that you attend. Proof of non-refundable fare is required!

- ***If you take side trips or travel outside of the defined travel days,*** your reimbursement shall be limited to **no more than** the state ceiling amount as noted on the enclosed Reimbursement Ceiling Chart.
- ***To eliminate the perception of misuse of government funds, FIRST CLASS, BUSINESS CLASS and REFUNDABLE AIRLINE TICKETS WILL NOT BE REIMBURSED AT FULL FARE,*** unless you request, in writing, an exception PRIOR to making your travel arrangements, and have received a written approval. Otherwise, your reimbursement will be limited up to the state ceiling amount.
- **It is your responsibility to find the cheapest ticket available.** Failure to do so may result in your reimbursement being limited to the state ceiling amount.

- **Use of frequent flier miles** toward the purchase of a ticket is **NOT** reimbursable.
- **Flight or ticket insurance is not reimbursable.**
- If any portion of your airfare is subsidized by another source, that portion is **NOT** reimbursable under the Stipend program.

If I drive, what will I be reimbursed? You will be reimbursed the current Privately Owned Vehicle (POV) Federal mileage allowance, or the state ceiling, **WHICHEVER IS LESS.**

- POV mileage is subject to validation.
- **If you do not register your vehicle with the Housing Office,** reimbursement for POV mileage may be denied.
- **If someone is dropping you off,** you *must* have the vehicle verified by the Housing office prior to the vehicle departing campus, or your stipend will be denied.
- If you carpool with another student, only the driver will be reimbursed.
- If you drove a rental car instead of your POV, your reimbursement is limited to the POV allowance.

If I take a train or bus, what will I be reimbursed?

- Your reimbursement is limited **to the cost of the ticket**, not to exceed the state ceiling **amount.**
- You must provide copies of the tickets actually used.
- Reimbursement shall not include costs for sleep accommodations or for transport of vehicles on the train.

If I save money on my airfare, will I be reimbursed for extra expenses? Yes, but **ONLY** if your class is **5 days or less in length with no Saturday stay over**, and you save a **minimum of \$250** off the cost of a 21-day prior to the course travel date pre-purchase non-refundable round trip economy class common carrier ticket. To do this, submit **written** documentation of the savings -- this can consist of itinerary copies of both the original price and the cheaper fare, OR copies of both fares from the Internet. Comparisons should be of like travel. If you do not acquire written approval from Admissions **prior** making your travel arrangements, the extra expenses **will not** be reimbursed. The following options apply if your request is approved:

a.) You may stay on campus 1 night prior to your regularly scheduled arrival date if lodging is available and you have received written approval to do so.

- Please contact the NETC Transportation Department to see if there will be shuttle service available on your travel date. If you carpool using a rental car, the rental agency must list (as drivers) all eligible students claiming reimbursement on the rental agreement or only the driver will be reimbursed.

b.) You may stay in the Baltimore/DC metro areas before or after your course.

- If you save at least \$250.00 in airfare as noted in the terms above, you may be reimbursed up to \$90/day (2-day limit for savings over \$500) for lodging or transportation expenses. **Original** receipts must be provided. If you carpool **from the airport** using a rental car, all students claiming reimbursement must be listed (as drivers), by the rental agency on the rental agreement or only the driver will be reimbursed.
- If you stay after your course ends, ask for a Stipend Agreement Amendment (FEMA Form 75-3a) when you register. When you return home, mail it with **original hotel or transportation** receipts to Admissions, Room I-216, 16825 South Seton Avenue, Emmitsburg, MD 21727 within 60 days of the start date of the course, or reimbursement **WILL BE DENIED.**



FOOD SERVICE



Must I purchase a meal ticket?

- If you stay on campus, you **must** purchase a meal ticket. **If you do not, you will be asked to vacate your room on campus. You will then be responsible for your off-campus lodging costs, and we will deny your request for stipend reimbursement.**
- If you stay off campus, you **must** purchase a break ticket, currently \$3 per day.

What is the cost of my meal ticket?

- Your meal ticket cost is identified in your acceptance letter.
- Meals other than those included in your meal ticket are to be paid for by cash.

What if I'm here for back-to-back courses?

- Your meal ticket includes the time between the two courses.
- If you stay off campus between the two courses (vacating your room), you must notify the food service Contractor **before** purchasing your meal ticket for the first course. If you do not, you will be charged the full amount. (*Refer to information under "Registration."*)

How do I pay for my meals?

- Cash
- Traveler's checks
- State or Local government checks payable to the food service contractor
- Advanced payment by department check. **Please notify your department to include: your name, course code and course date on the check**, and send it to the food service contractor at Building K, 16825 South Seton Avenue, Emmitsburg, MD 21727. Please call the food service if you need their Federal Tax ID#.
- Purchase order payable to the food service contractor
- Credit card (MasterCard or VISA) (Minimum charge of \$6)
- **The food service contractor DOES NOT accept personal checks.**

What if I will not be on campus for the first and last meal identified as part of my meal ticket? You must notify the food service contractor at least 1 week prior to your course start date. If you do not, you will be obligated to pay the full amount.

May I get a refund on my meal ticket? There are no refunds except for emergency departures!

What if I'm on a special diet? Please call the food service contractor or fax your request to (301) 447-6944 at least 2 weeks prior to arriving at NETC. They will make arrangements to meet your needs. If you don't make arrangements prior to your arrival, you will be responsible for purchasing the normal meal ticket.

What happens if the bus arrives after the dining hall has closed?

- The food service contractor will provide you with a boxed dinner.
- Snack food is available at the Command Post Pub.

CONTACT INFORMATION

How do I get a telephone call? The caller may dial your direct extension (301) 447-xxxx. If requested, you will be provided with your extension at check-in. Numbers are NOT given to anyone else.

- For non-emergency situations, the caller may dial (301) 447-1048. The Student Coordinator will either transfer the call to your room or take a message and place it on the message board located in 'C' Lobby, which you should check daily.
- ***NETC will not accept personal telephone calls to students from the (800) number.*** Family members should dial (301) 447-1000 to contact a student.
- ***You may NOT accept collect calls.*** To do so may restrict you from attending future EMI or NFA courses.

What if the call is an emergency?

- The caller should state that the call is an emergency.
- The message will be delivered to you immediately unless you are not on campus.
- If you are leaving campus for a period of time, you should notify security where you can be reached.
- If you must return home due to an emergency, check out with the Housing Office in Building C before you depart the campus!

How do I get mail?

- Mail is delivered to C Lobby Monday through Friday, except Federal holidays.
- All packages are x-rayed and no delivery is provided on weekends or holidays.
- Letters or packages should not be mailed to reach NETC ***before*** you arrive, since mail-holding areas are not available. Mail received when you are not on campus will be automatically returned to the sender.
- Outgoing mail should be deposited in the mailbox located near Building K (Dining Hall). The NETC Mailroom cannot mail outgoing items for students.
- Address:

(Your name)--Student
National Emergency Training Center
Building C, Room (**Room numbers are provided upon arrival**)
16825 South Seton Avenue
Emmitsburg, MD 21727-8998



National Emergency Training Center
16825 South Seton Avenue
Emmitsburg, Maryland 21727

FREQUENTLY ASKED REIMBURSEMENT QUESTIONS

1. **Why must I be reimbursed electronically?** Public Law 104-134 mandates that after January 1, 1999, all Federal payments shall be made by electronic funds transfer unless a waiver is obtained from the Secretary of the Treasury.
2. **If my organization paid for my ticket, may I request that the reimbursement go to them?** Due to increased restrictions by the receiving financial institutions, money should only be deposited into an account bearing your name. You may then reimburse your organization.
3. **What if I don't have a checking account?** The money can be deposited into a savings account. Please call the Admissions Office (301-447-1035) and we will send you a form to complete. If you don't have a checking or savings account, you **MUST** submit a letter stating that fact, and a check will be sent to your home address. However, your reimbursement may take longer up to 12 weeks.
4. **How will I know when it's deposited?** The entry in an account may differ from bank to bank, but most likely it will be listed as "FED SALARY, FEM2, or TREAS" and will probably **NOT** have your name next to it.
5. **How long will it take for me to receive reimbursement?** The reimbursement should be made to your account no later than 6-8 weeks from the course start date. If after 8 weeks you still haven't received your reimbursement, please call the Admissions Office at (301) 447-1035 or email us at netc-admissions@dhs.gov to check on the status of your claim.
6. **What would delay my stipend being processed?** Not having any of the following: 1) your airline ticket; 2) itinerary with ticket number and payment made (ticket number pending is not acceptable); 3) POV information; 4) request from your organization for reimbursement or 5) the appropriate direct deposit information. If you bank with a credit union, please have them confirm your routing and account numbers.
7. **What would reduce my stipend claim?** Your stipend might be reduced if you purchased a refundable, first- or business-class ticket; took side trips or had extended stays; or purchased your ticket within 21 days prior to the course travel date.
8. **What if I am submitting an electronic airline ticket?** You must submit the itinerary receipt (listing the ticket number and showing that payment was made) at registration. If the itinerary does not identify that the ticket is non-refundable, you need to provide us with documentation that the ticket is either non-refundable or the cheapest fare available at the time you purchased your ticket. If you do not provide the documentation to us, we will only reimburse up to your state's ceiling amount.
9. **Will I be reimbursed for the airfare if frequent flyer miles are used?** Frequent flyer miles cannot be reimbursed because you would not be incurring out-of-pocket expenses.
10. **What do I need to provide if I take a side/extended trip?** If the cost is less than your state's ceiling amount, you will be reimbursed for the cost of the ticket. If the cost is higher than your state's ceiling amount, your reimbursement will be limited to your state's ceiling amount.
11. **Do I receive reimbursement for parking, shuttles and travel between my home and my local airport?** No, those expenses are part of the student's share of the stipend program.
12. **Will I be reimbursed for my meals?** No, that expense is also part of the student's share of the stipend program.
13. **What is the driving mileage allowance?** Your reimbursement will be limited to the current POV Federal mileage allowance, or the state ceiling, **WHICHEVER IS LESS**. POV mileage is subject to validation.
14. **What information should I bring when driving my Privately Owned Vehicle (POV)?** You must show a picture ID (we recommend you bring two in case our security level is elevated), registration card, and have your odometer readings and license tag number **PRIOR** to receiving your room key. Some states do not require the registration to be in the vehicle. However, you must submit a copy of your POV registration to be eligible for a stipend.
15. **What documentation do I need if I am driving my organizational vehicle and they want to be reimbursed for my mileage?** In addition to the information listed in question #14, you also need a statement from your organization, on organization letterhead, stating that you are authorized to drive the vehicle and they would like you to receive reimbursement. If you carpool with another student, only one driver will be reimbursed. As stated in #2, the reimbursement will be made to your account. You will be responsible for reimbursing your organization.
16. **What if I'm driving with family, and they will be using the car off campus while I'm at NETC?** You must register your car on campus prior to your family taking the car off campus or you will not be eligible for reimbursement.

THIS TABLE WILL BE USED TO DETERMINE REIMBURSEMENT FOR NETC STUDENTS WHO:

- Drove or traveled by bus or train
- Did not purchase or show proof of non-refundable fare
- Purchased tickets less than 21 days prior to course travel date
- Took side-trips or had extended stayovers

STATE	SAT STAYOVER	NO SAT. STAYOVER
AK – Alaska	\$855.00	\$920.00
AL – Alabama	\$365.00	\$405.00
AR – Arkansas	\$360.00	\$500.00
AS—American Samoa	\$2275.00	\$2275.00
AZ – Arizona	\$480.00	\$535.00
CA – California	\$470.00	\$545.00
CO – Colorado	\$400.00	\$430.00
CT – Connecticut	\$215.00	\$300.00
DC – District of Columbia	\$100.00	\$100.00
DE – Delaware	\$145.00	\$145.00
FL – Florida	\$375.00	\$480.00
GA – Georgia	\$330.00	\$440.00
GU—Guam	\$2170.00	\$2170.00
HI – Hawaii	\$1075.00	\$1105.00
IA – Iowa	\$365.00	\$445.00
ID – Idaho	\$520.00	\$535.00
IL – Illinois	\$260.00	\$375.00
IN – Indiana	\$270.00	\$270.00
KS – Kansas	\$325.00	\$370.00
KY – Kentucky	\$250.00	\$310.00
LA – Louisiana	\$430.00	\$430.00
MA – Massachusetts	\$200.00	\$285.00
MD – Maryland	\$100.00	\$100.00
ME – Maine	\$345.00	\$400.00
MI – Michigan	\$410.00	\$410.00
MN – Minnesota	\$400.00	\$500.00
MO – Missouri	\$310.00	\$360.00
MP—Saipan	\$2925.00	\$2925.00
MS – Mississippi	\$355.00	\$355.00
MT – Montana	\$600.00	\$600.00
NC – North Carolina	\$300.00	\$335.00
ND – North Dakota	\$505.00	\$650.00
NE – Nebraska	\$350.00	\$525.00
NH – New Hampshire	\$185.00	\$200.00
NJ – New Jersey	\$175.00	\$175.00
NM – New Mexico	\$435.00	\$435.00
NV – Nevada	\$450.00	\$520.00
NY – New York	\$220.00	\$210.00
OH – Ohio	\$270.00	\$270.00
OK – Oklahoma	\$350.00	\$465.00
OR – Oregon	\$470.00	\$480.00
PA – Pennsylvania	\$145.00	\$145.00
PR—Puerto Rico	\$800.00	\$800.00
RI – Rhode Island	\$200.00	\$200.00
SC – South Carolina	\$325.00	\$300.00
SD – South Dakota	\$550.00	\$550.00
TN – Tennessee	\$335.00	\$335.00
TX – Texas	\$400.00	\$410.00
UT – Utah	\$505.00	\$505.00
VA – Virginia	\$175.00	\$190.00
VI—Virgin Islands	\$905.00	\$905.00
VT – Vermont	\$300.00	\$340.00
WA – Washington	\$500.00	\$500.00
WI – Wisconsin	\$300.00	\$355.00
WV – West Virginia	\$200.00	\$200.00
WY – Wyoming	\$590.00	\$600.00